Development of Ecological Indicator Guilds for Land Management

CS-1114B

Research Team

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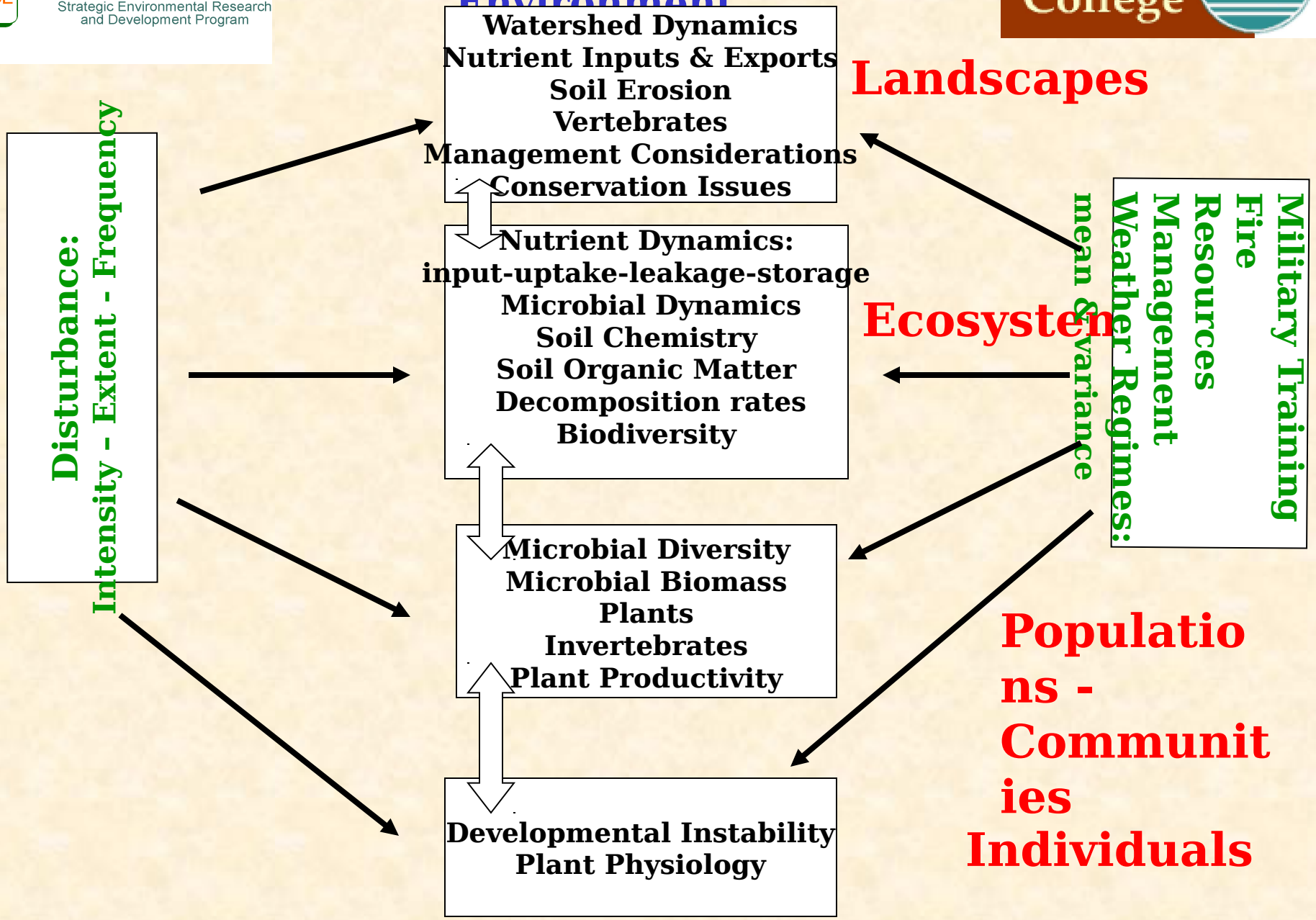
Technical Objectives

- **Develop Ecological Indicators To**
  - **Track and monitor ecological changes**
  - **Provide early-warning or threshold detection**
  - **Quantify habitat condition and trends**
- **Based On**
  - **Simple metrics**
  - **Derived from associations with Ecological Processes, Community Attributes, and Physiological Stress**
  - **Based on classifying similar responses to Ecological Indicator Systems (Guild Construction)**

Technical Background

- **Indicators have been used for over a century But never in an integrated holistic ecological framework**
- **Ecological Guilds have been used to classify species based on similar trophic roles (e.g., food habits, foraging methods)**
- **This research uses guilds to classify Ecological Indicator Systems by their similar responses to disturbance and stressors**

Integration: Ecological Indicators, Disturbance, Environment



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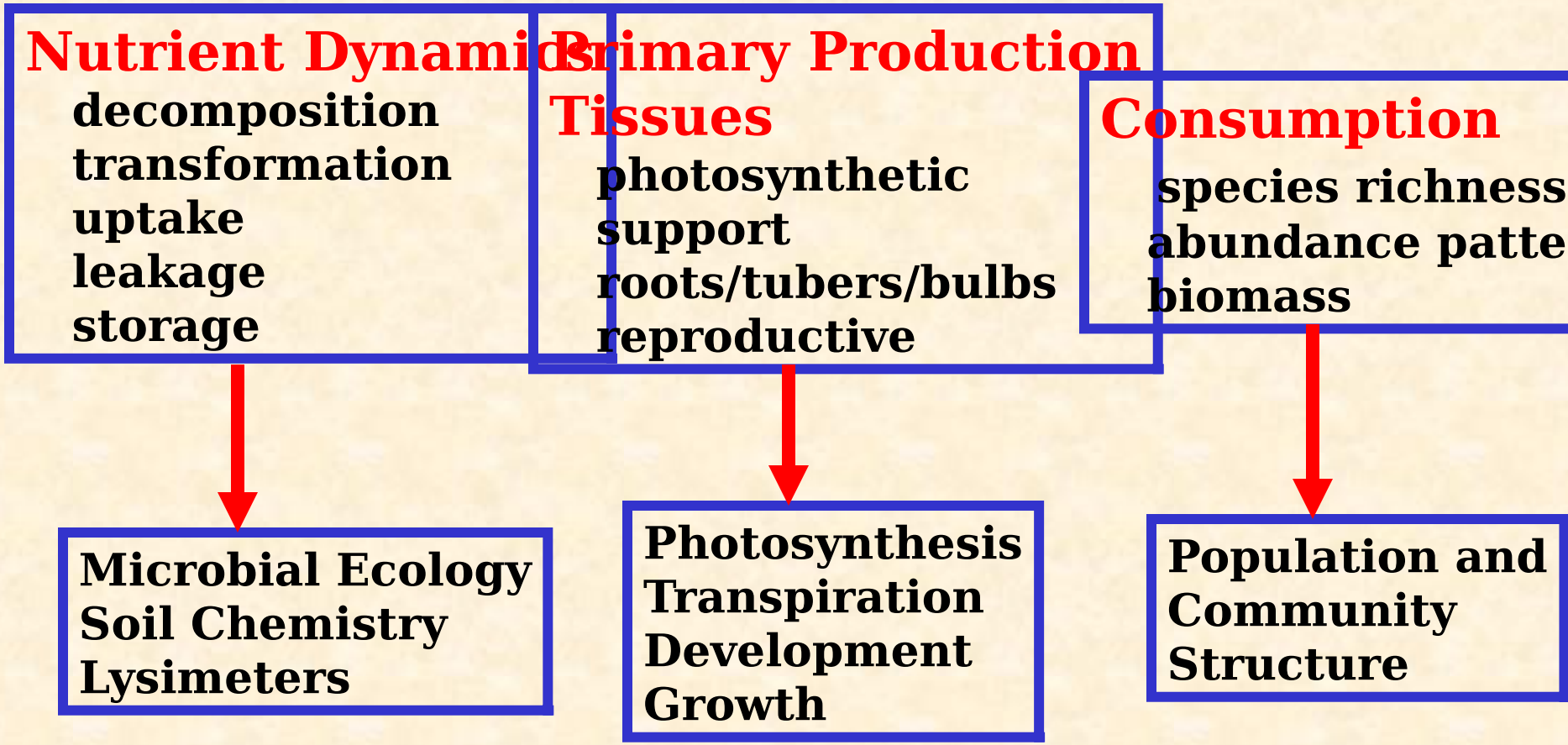
Ecological Processes

Linking Below Ground and Above Ground Components



Field and Lab Measurements

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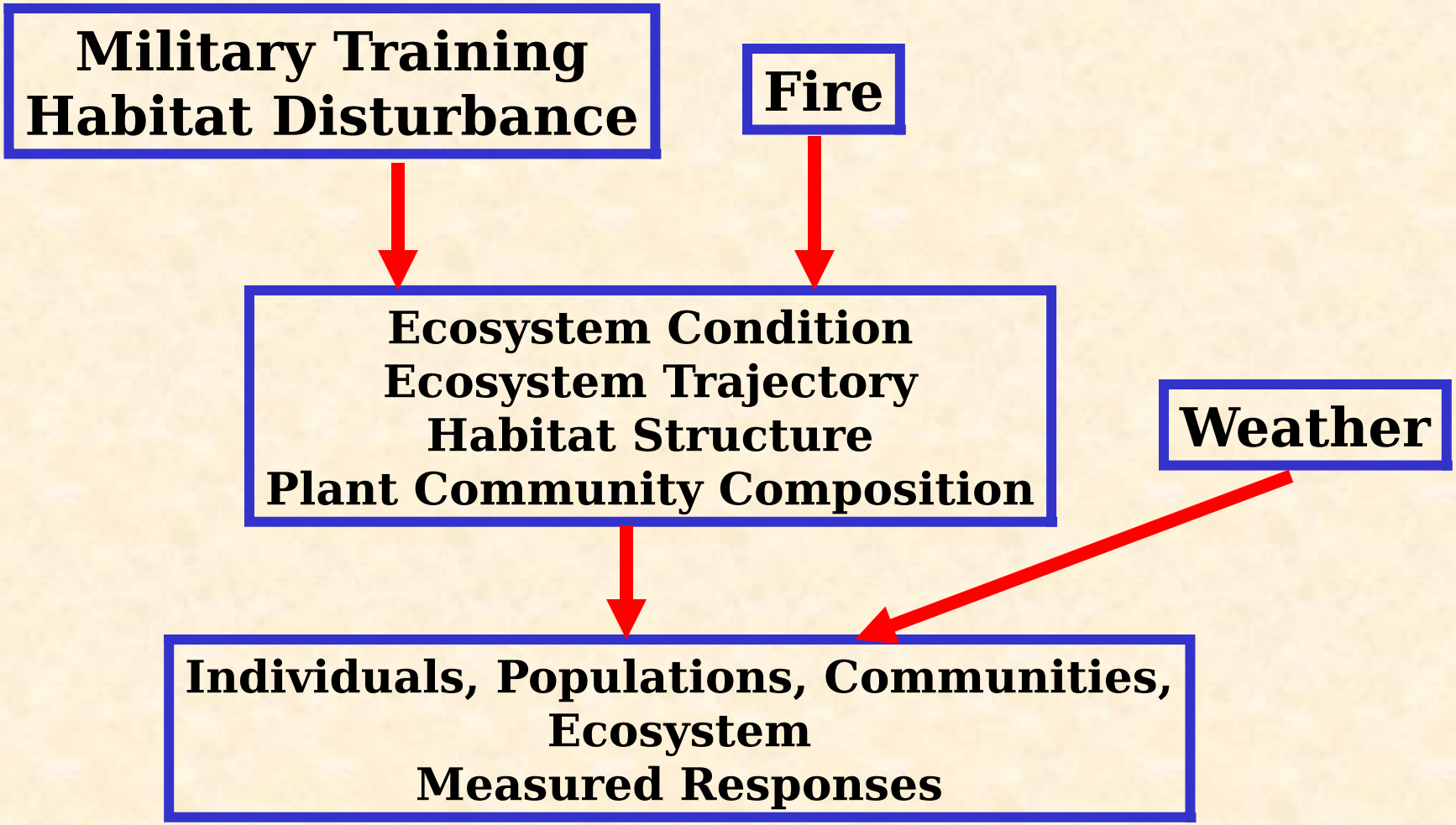
Disturbance to Ecological Systems are Complex



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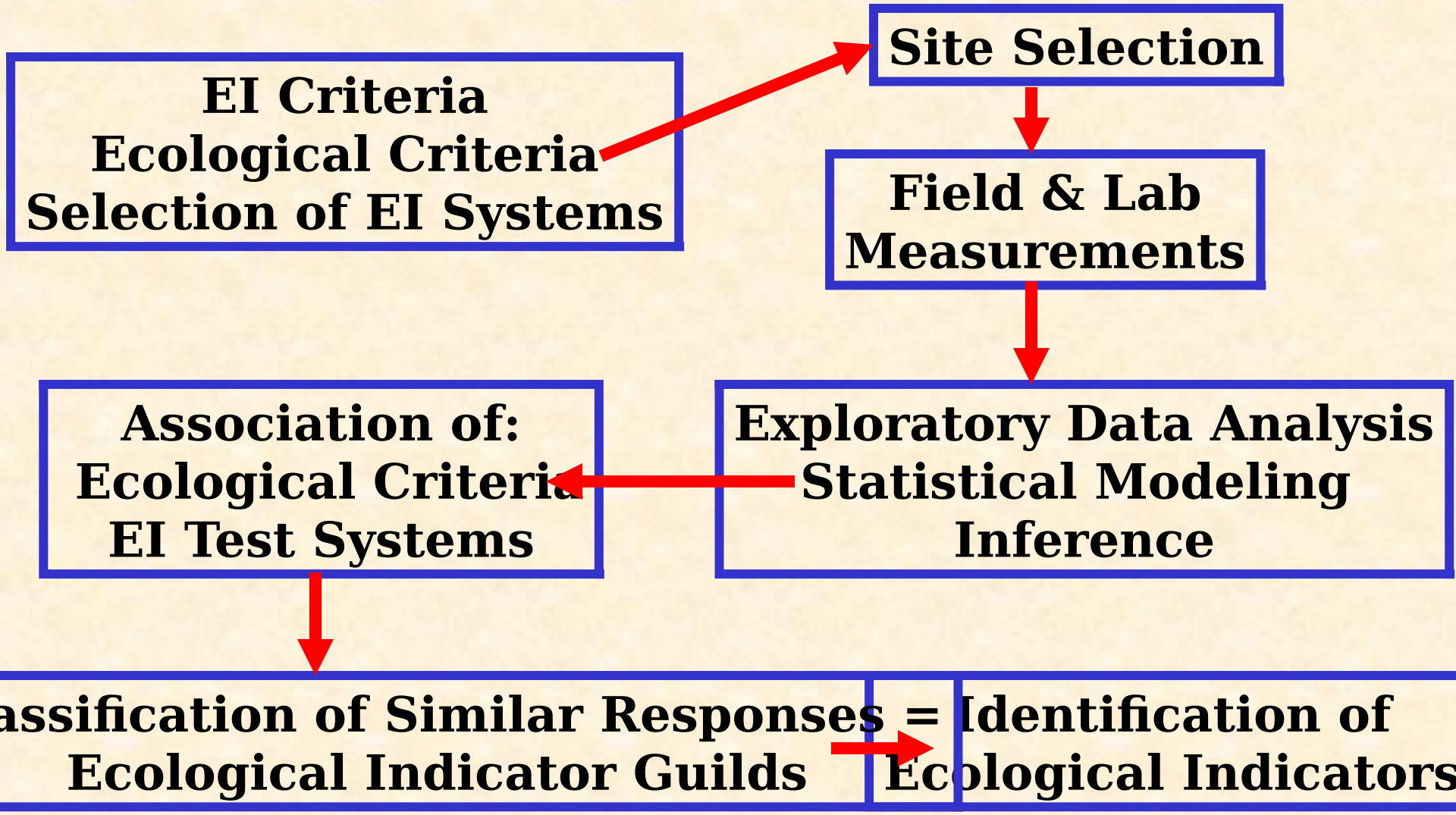
Technical Approach

Ecological Indicators (EI)



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Analysis and Modeling
Exploratory, Inference, Ordinations

- **Traditional Parametric and Nonparametric**
- **Discriminant Analysis**
- **Principal Components Analysis**
- **NonMetric Multidimensional Scaling**
- **Canonical Correspondence Analysis**
- **Detrended Correspondence Analysis**
- **Meta Analysis**
- **Community and Spatial Metrics**
- **Structural Equation Modeling**

Research Project Setting

- **Fort Benning, Georgia**
  - **Uppermost Southeastern Coastal Plain**
  - **Sand Hills Physiography**
- **9 Research Sites in 2 Watersheds**
- **3 Sites in each "Disturbance Class"**
  - **HIGH – current mechanized infantry training activities**
  - **MEDIUM – past training, current foot traffic**
  - **LOW – never subjected to military training, occasional foot traffic**

Site Selection
Based on a Disturbance Gradient
3 sites selected in each disturbance class

High

Current mechanized-in training

H3

H1

Medium

Past training activities
Current foot traffic

M3

M1

Low

No military training
Minimal foot traffic

L2

L1

Analysis Strategy for Ecological Indicators

Ecological Indicator Criteria 1998 (Proposal)

↓

Ecological Indicator Systems 1999

↓

Ecological Indicator Subsystems 1999-2000

↓

Data – Analysis – Modeling 2000-2003

↓

Ecological Indicator Guilds 2003-2004

↓

Ecological Indicators for Land Management 2004

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Ecological Indicator Systems in Disturbance Gradient

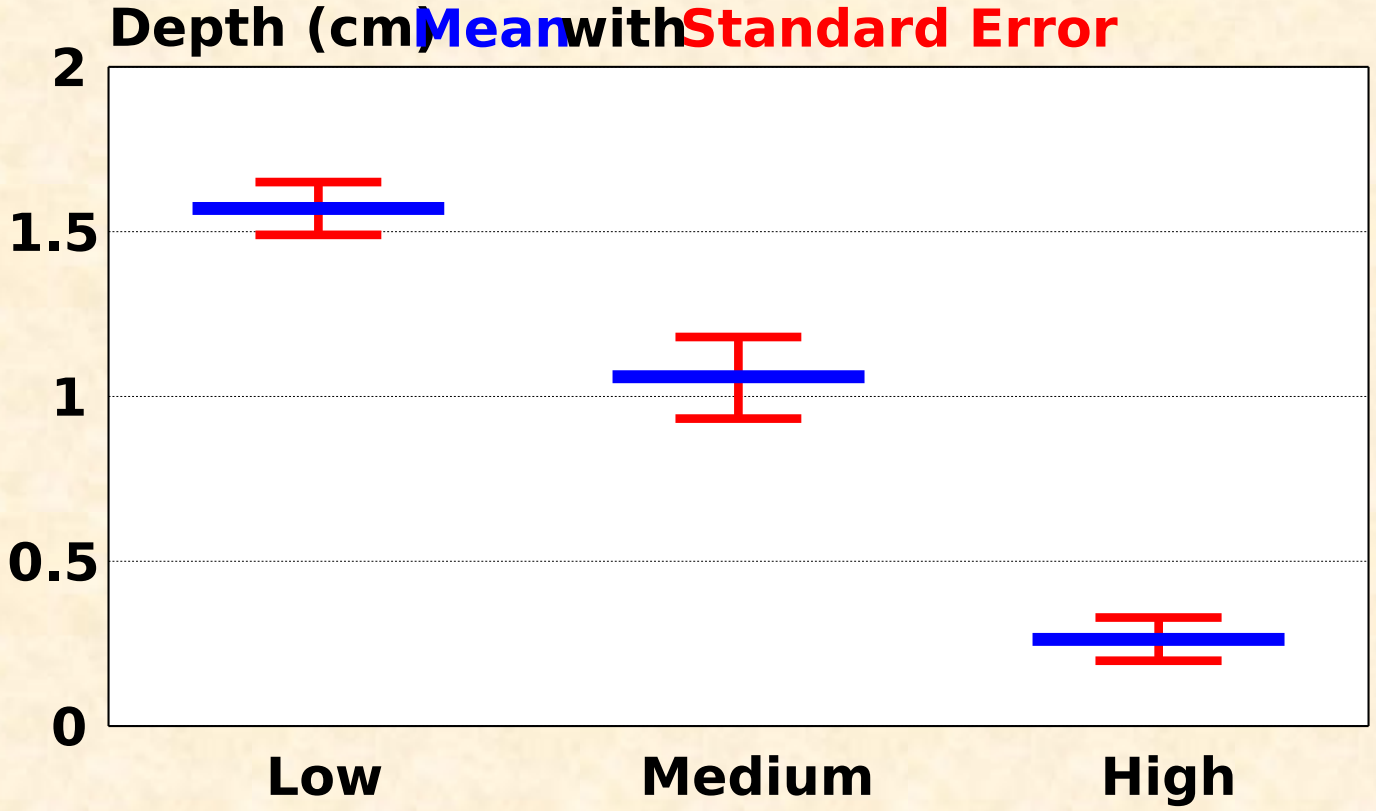
- **Habitat Characterization**
  - **Physiognomy, Floristics, Physical Soil Properties**
- **Litter and Soil Chemistry**
- **Nutrient Flux and Leakage**
- **Microbial Communities**
- **Invertebrate Communities**
- **Plant Physiological Responses**
- **Developmental Instability (DI)**
- **Plant Community Spatial Interactions**
- **Vertebrate Communities**

Habitat Characterization

- **General Habitat**
  - Canopy Cover
  - Tree Density
  - DBH (mean, std dev)
  - Basal Area (total, density/DBH classes)
  - A-Horizon Soil Depth
  - Soil Compaction
  - Soil Shear Stress
- **General Ground Cover**
  - Forbs
  - Legumes
  - Grass
  - Woody
  - Litter
  - Bare Ground
  - Woody Species
  - Richness
- **Woody Ground Community**
  - Taxa Cover: Woody, *Opuntia*, *Yucca*, *Pteridium*
- **Tree Community**
  - Taxa: density, mean & std dev of DBH

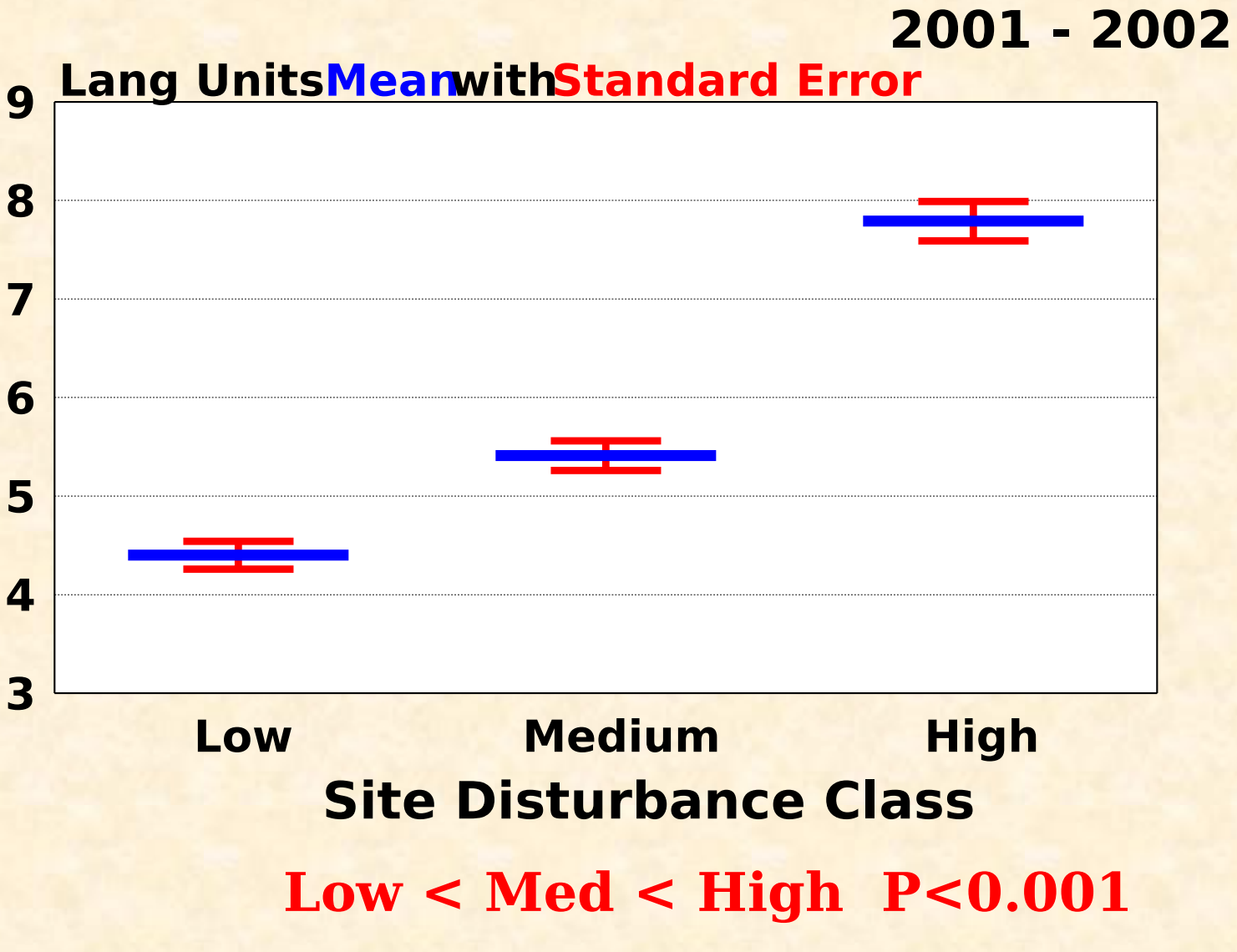
A-Horizon Soil Depth

2001 - 2002



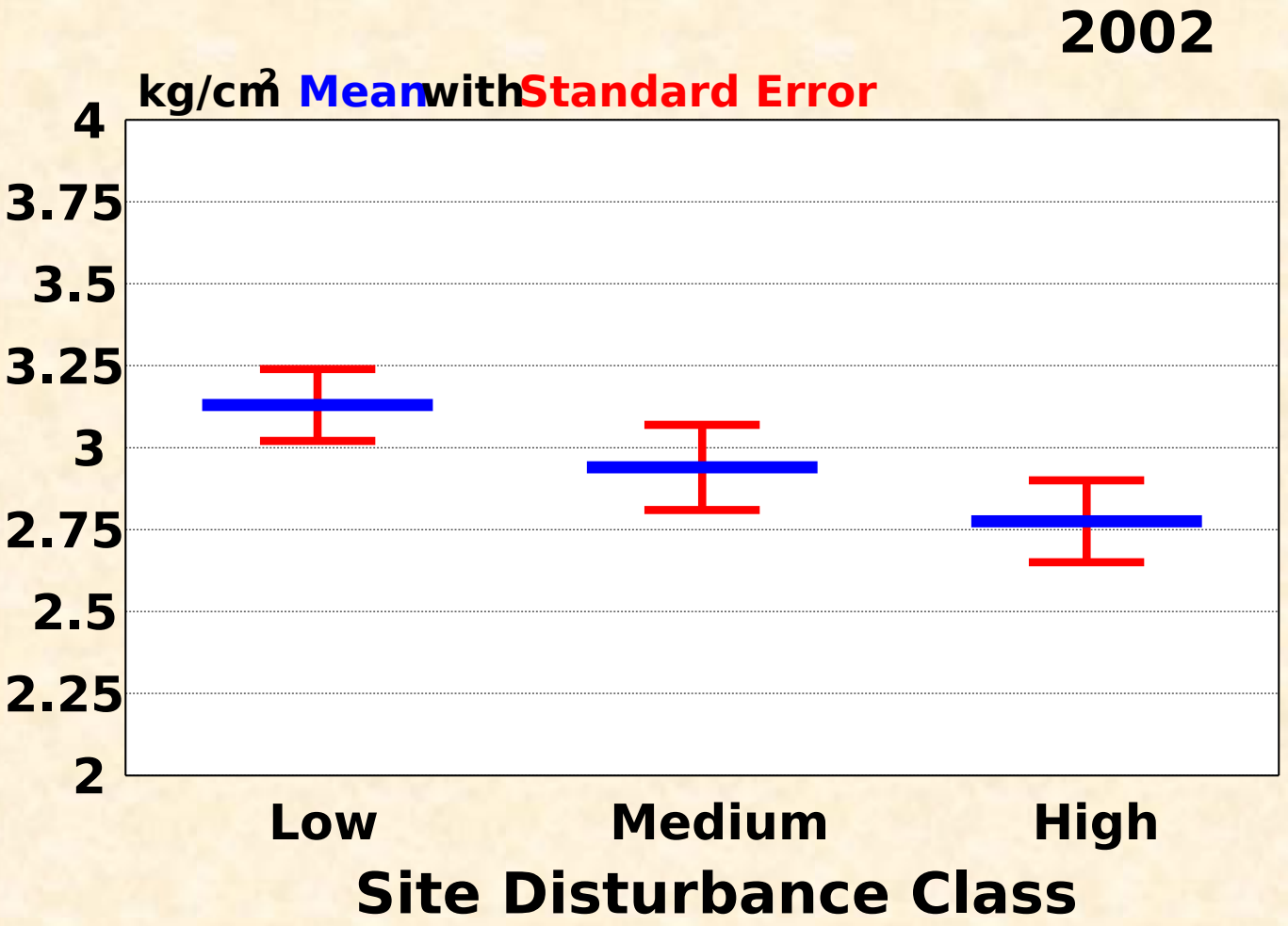
Low > Med > High P<0.001

Soil Compaction



Low < Med < High P<0.001

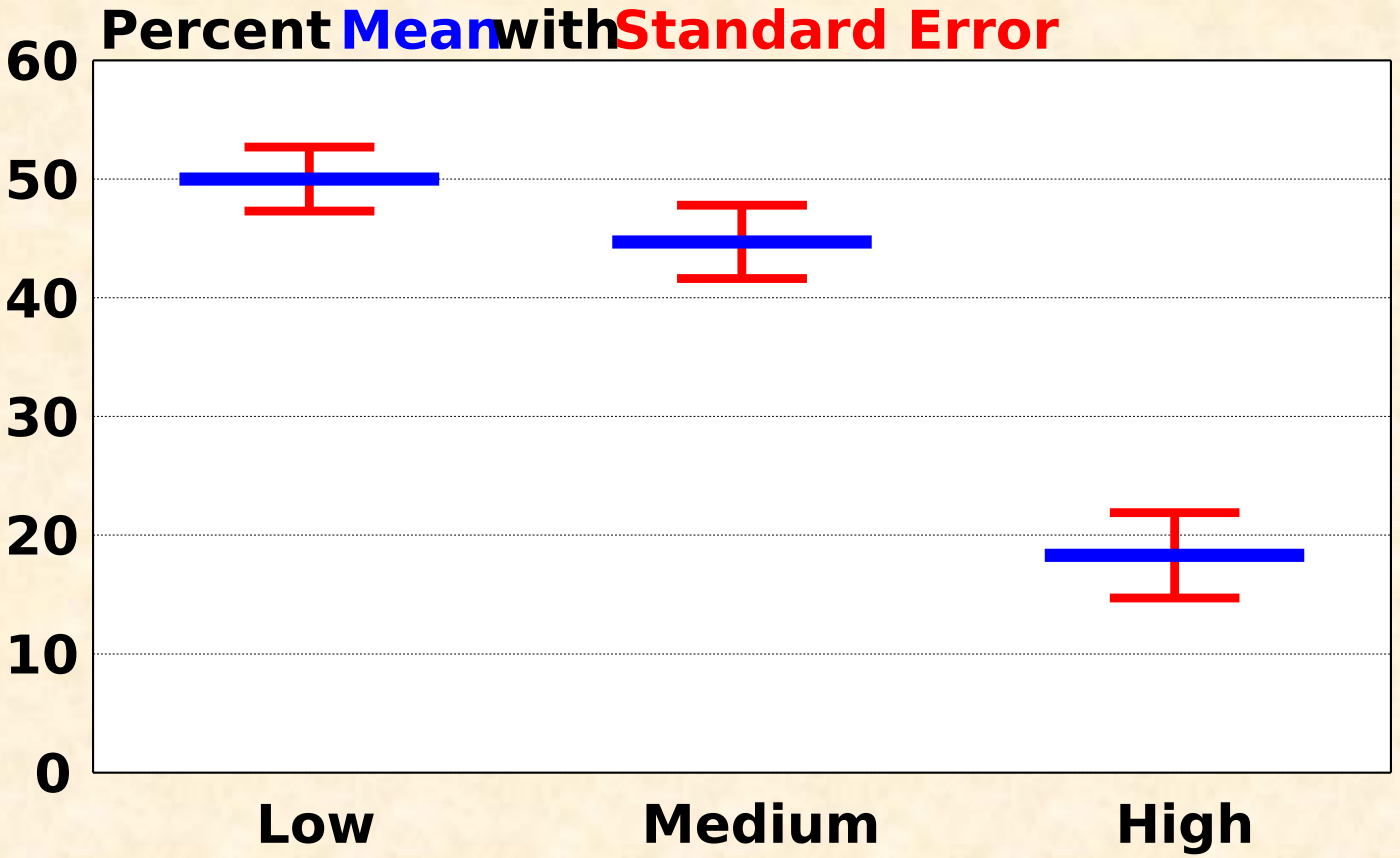
Soil Shear Stress



Low > High P=0.012

Canopy Cover

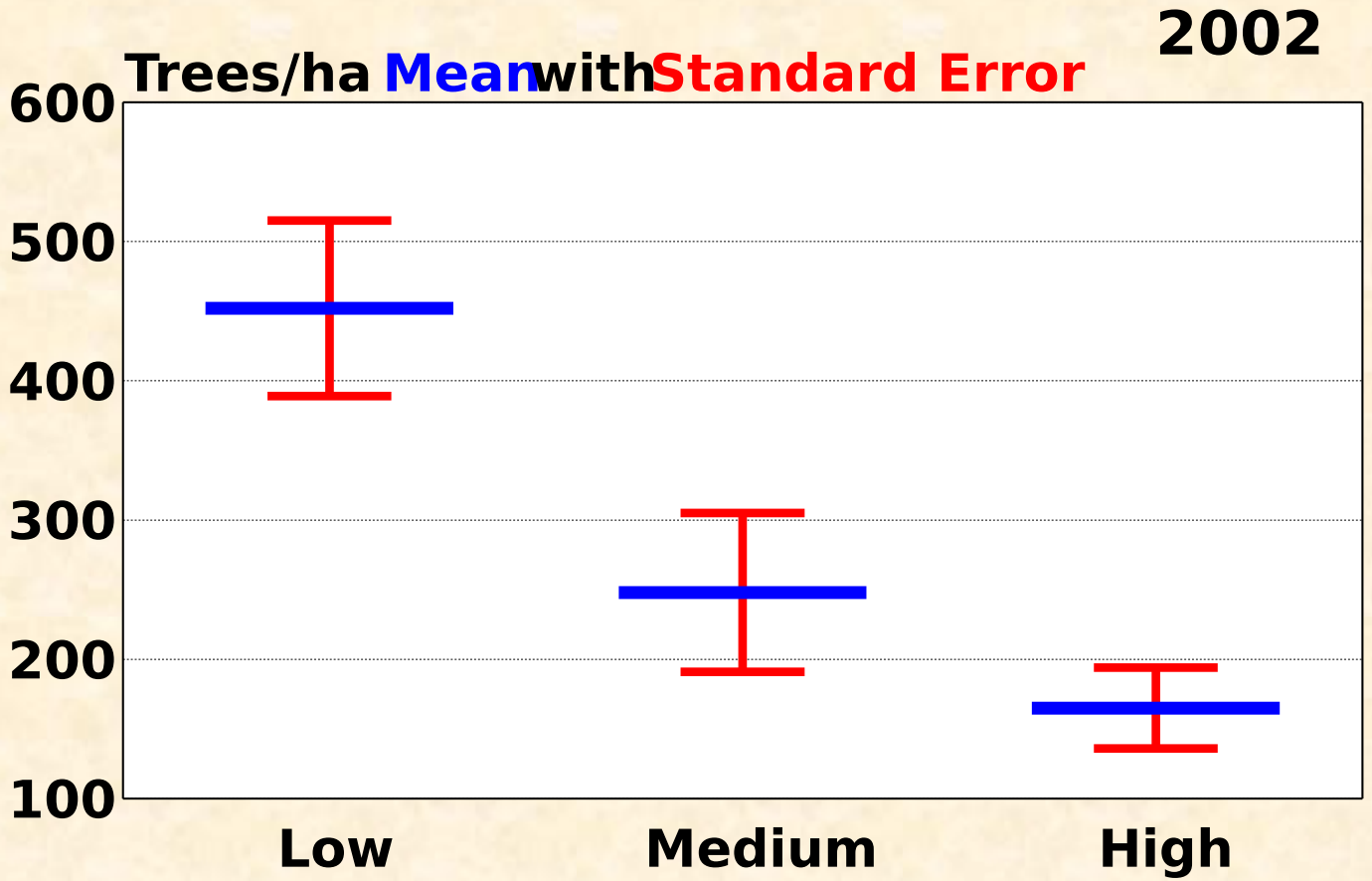
2001 - 2002



Low = Med > High P<0.001

Tree Density

DBH > 5 cm

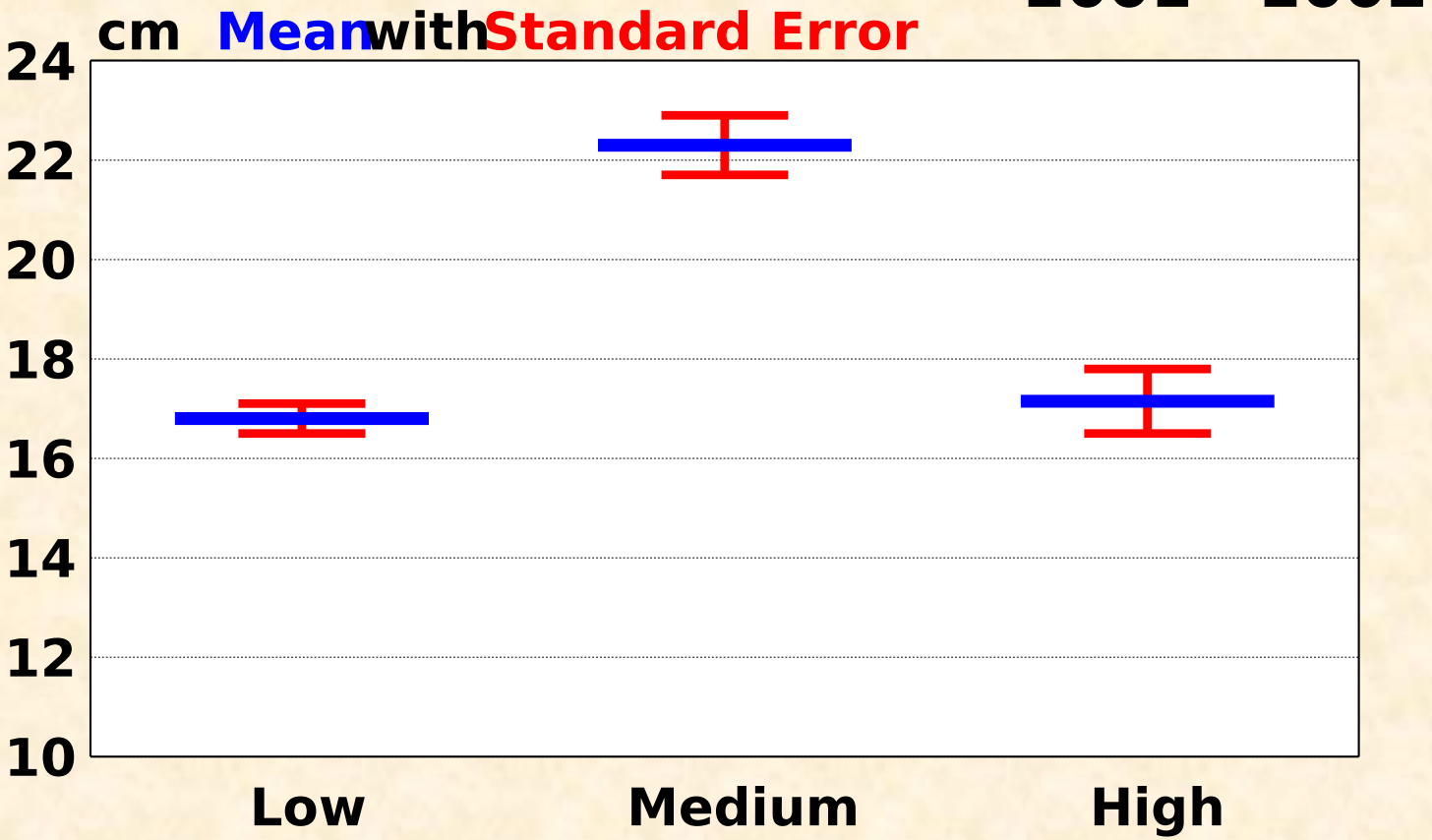


Low > Medium = High P=0.026

Tree DBH (Diameter Breast High)

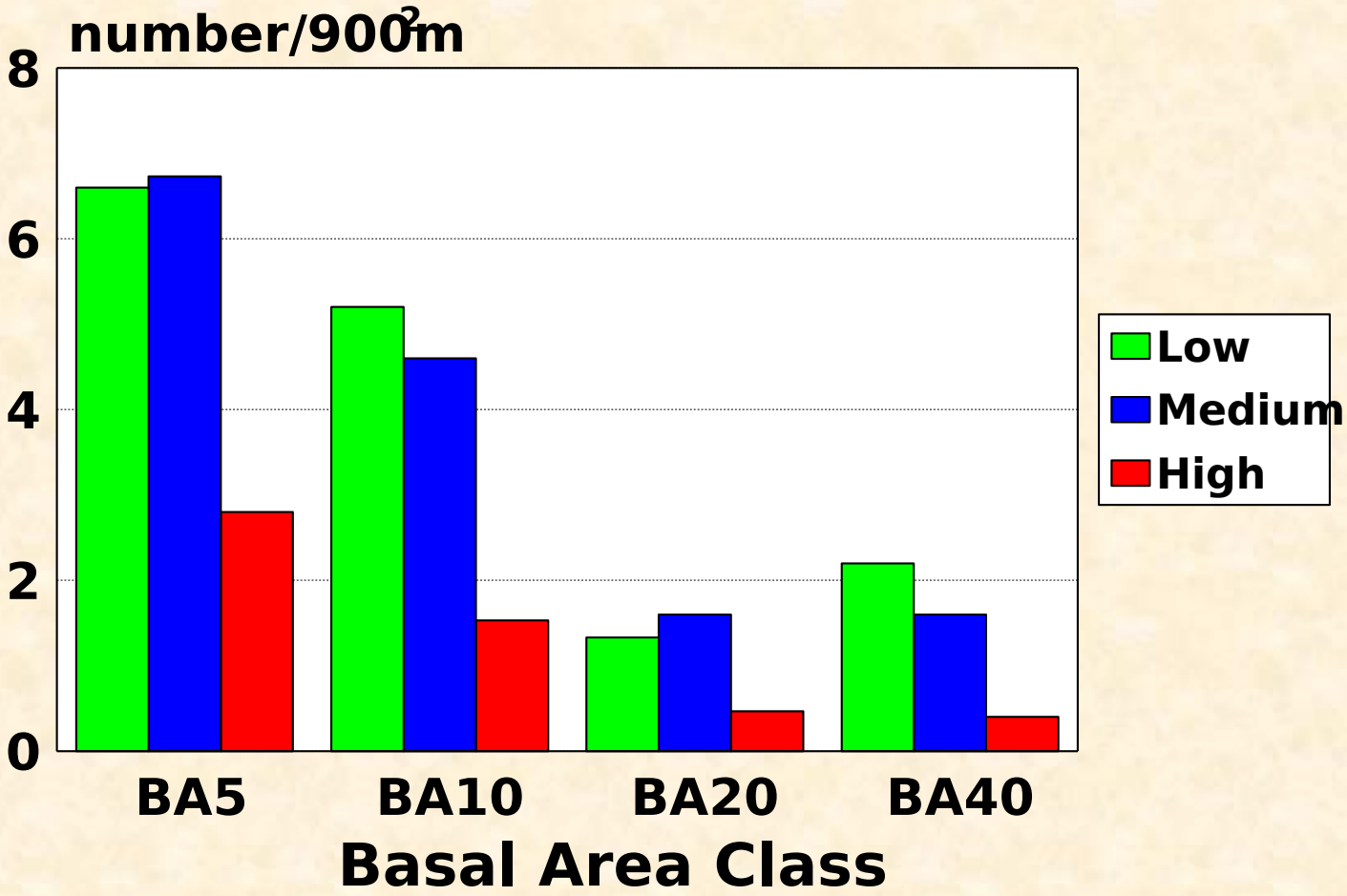
DBH > 5 cm

2001 - 2002

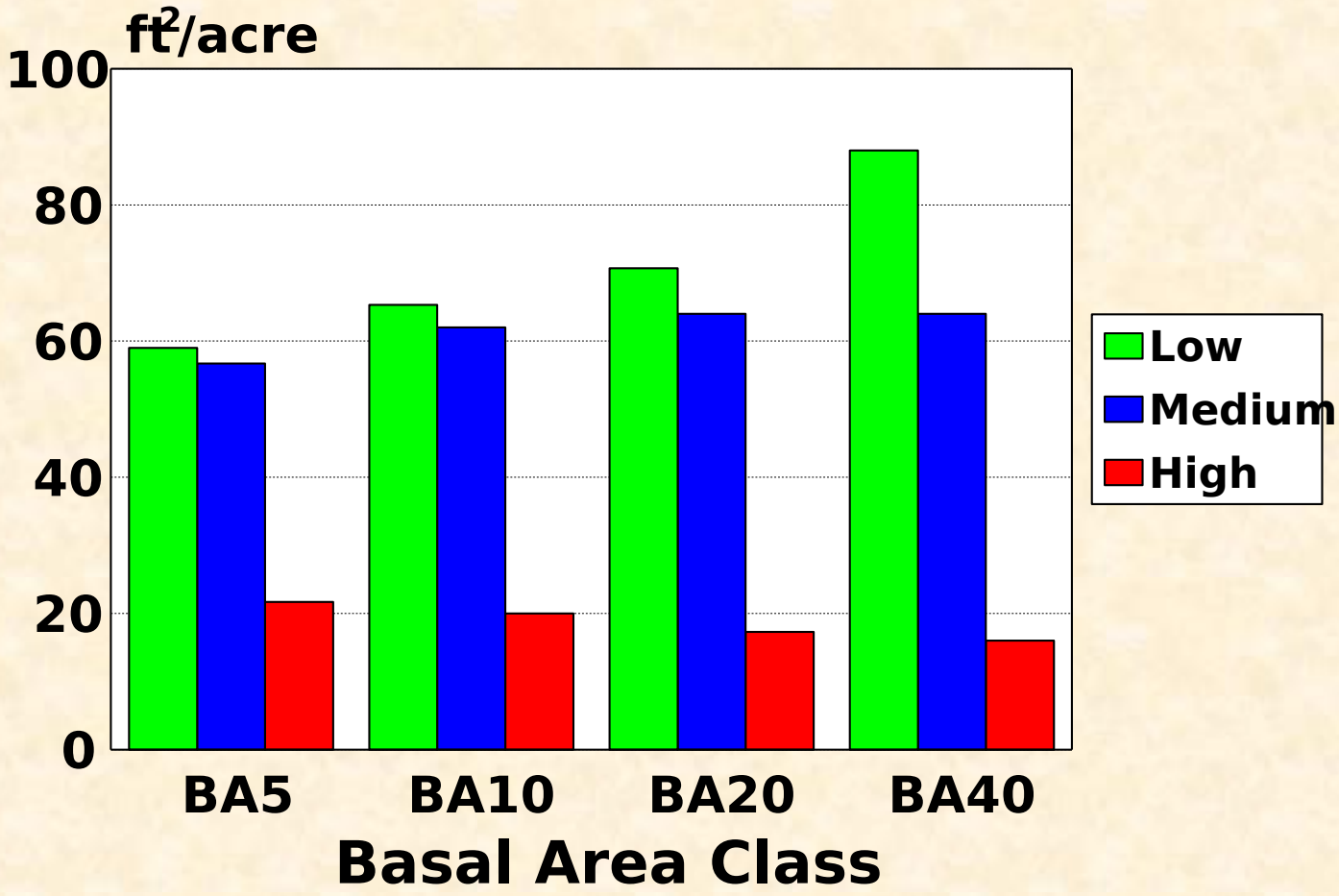


Med > Low = High P<0.001

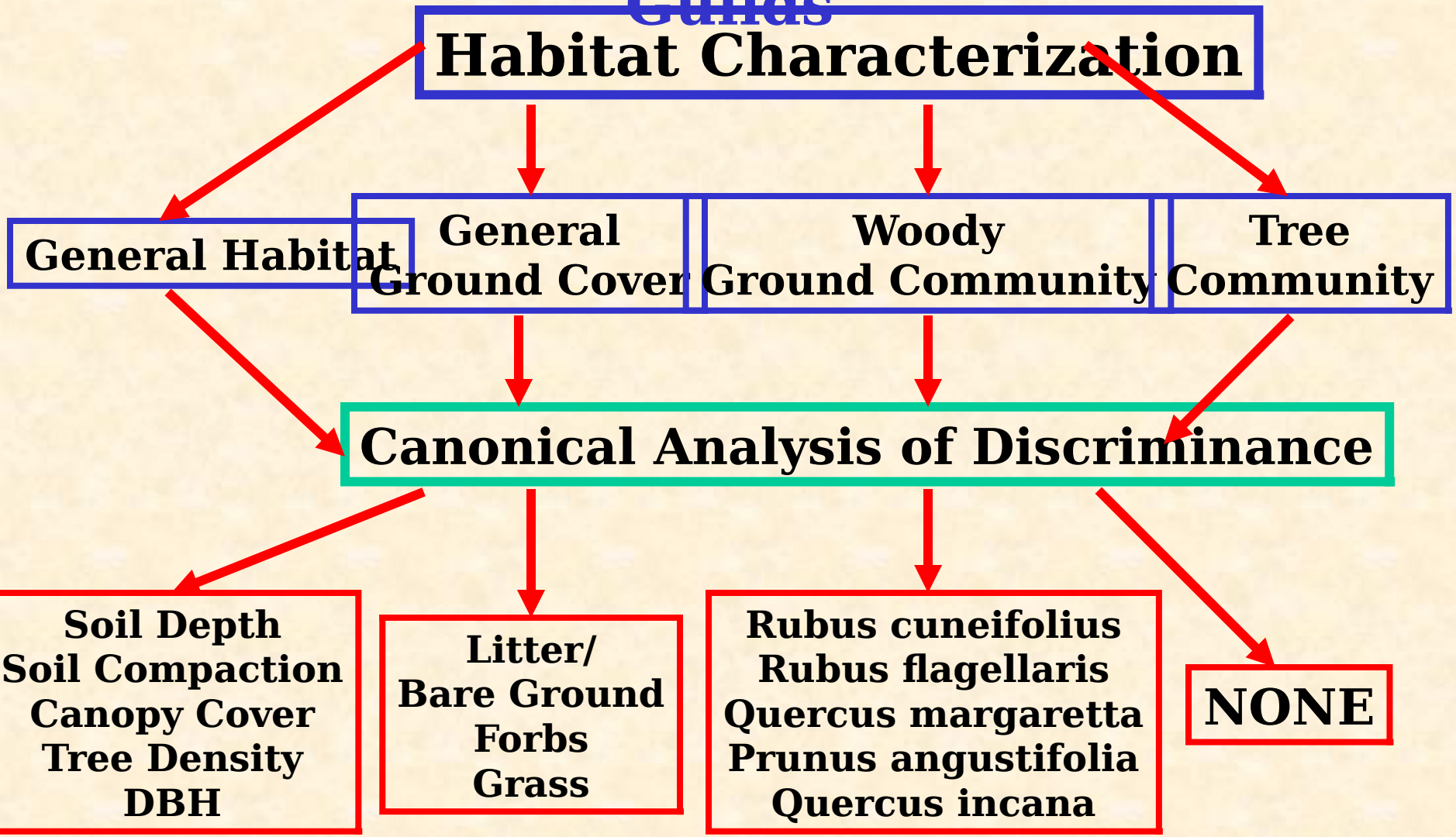
Basal Area Classes



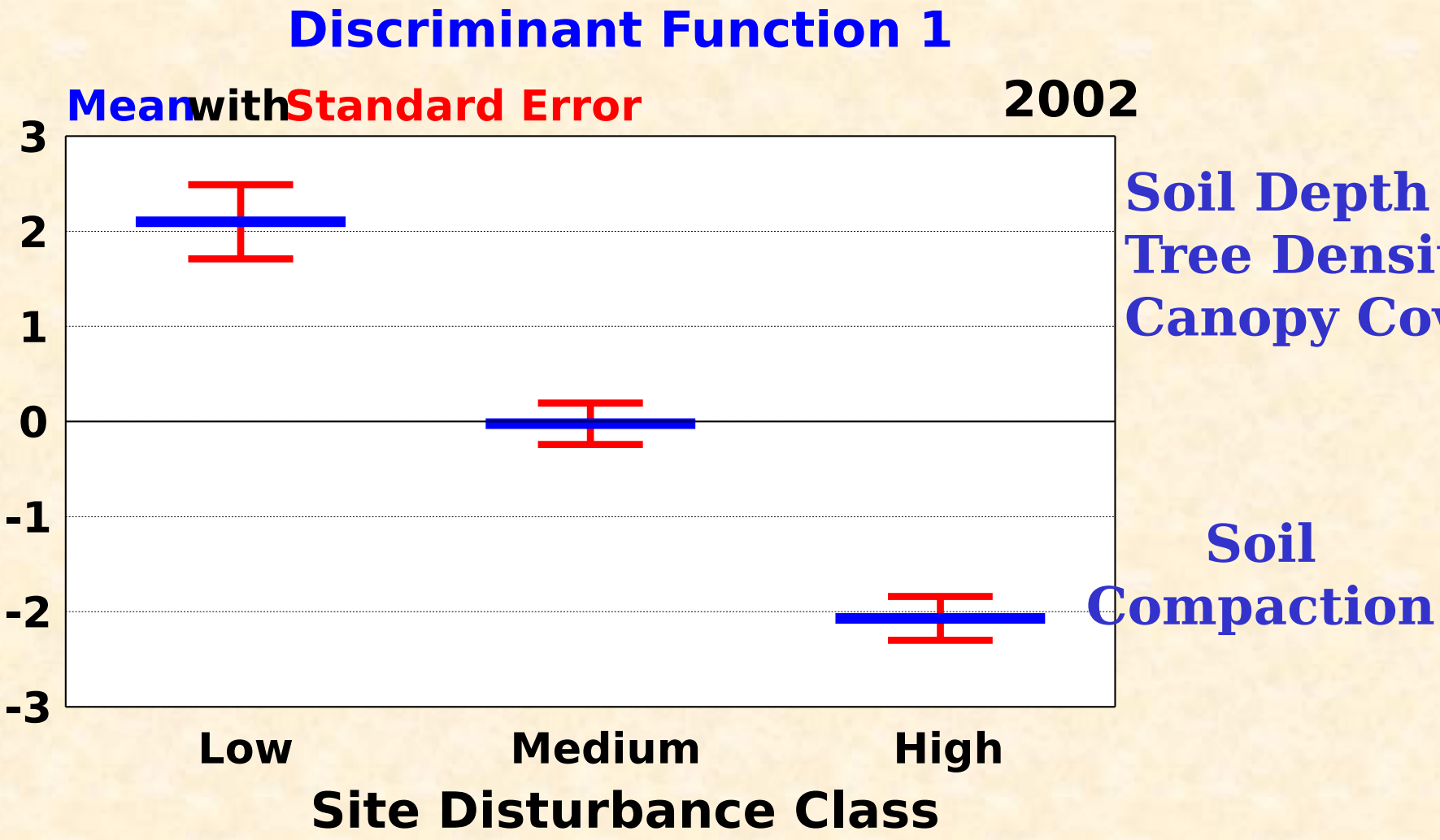
Basal Area of Trees



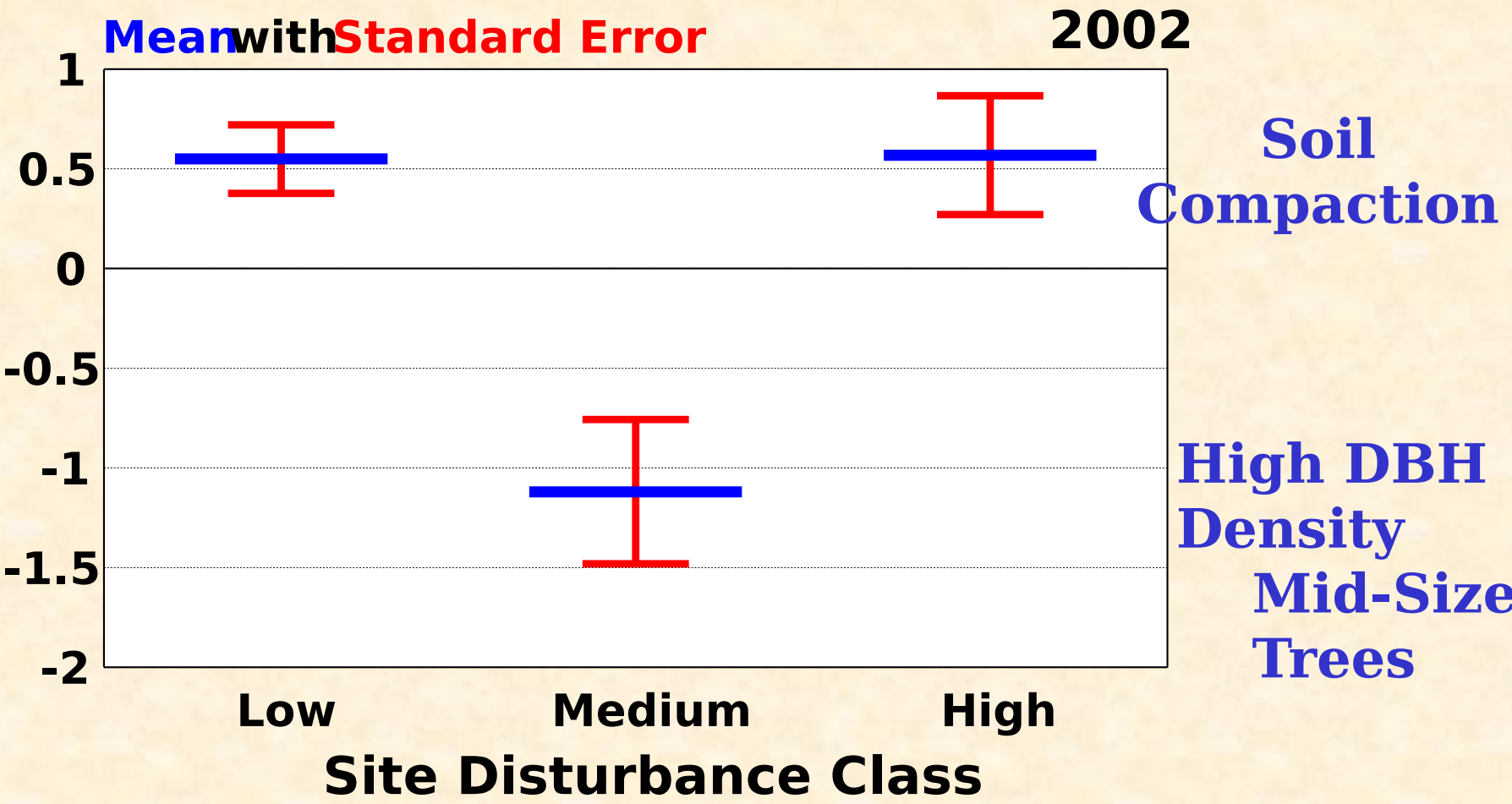
Constructing Ecological Indicator Guilds



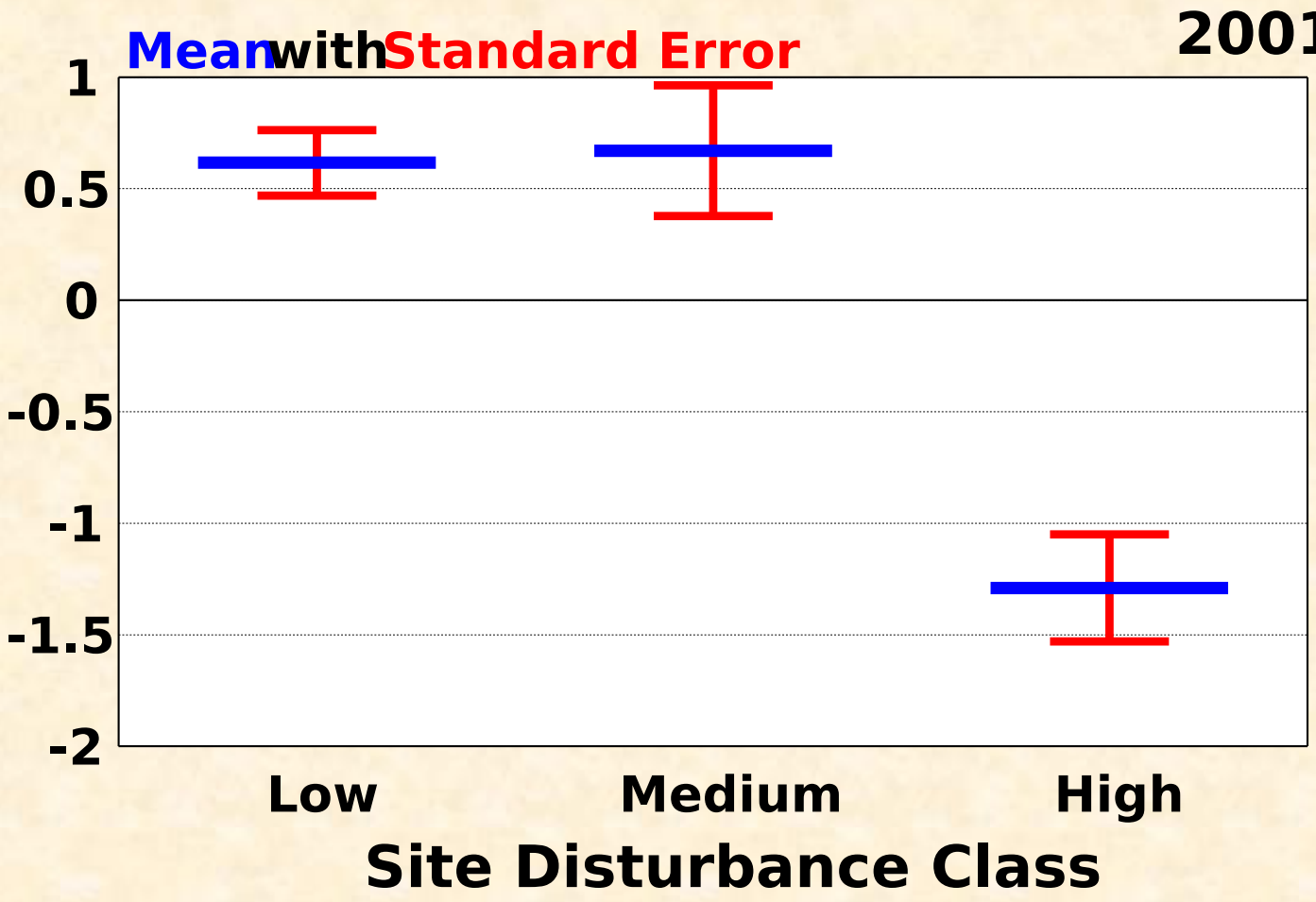
General Habitat Variables



General Habitat Variables



General Ground Cover Variables



Litter

Woody Cover

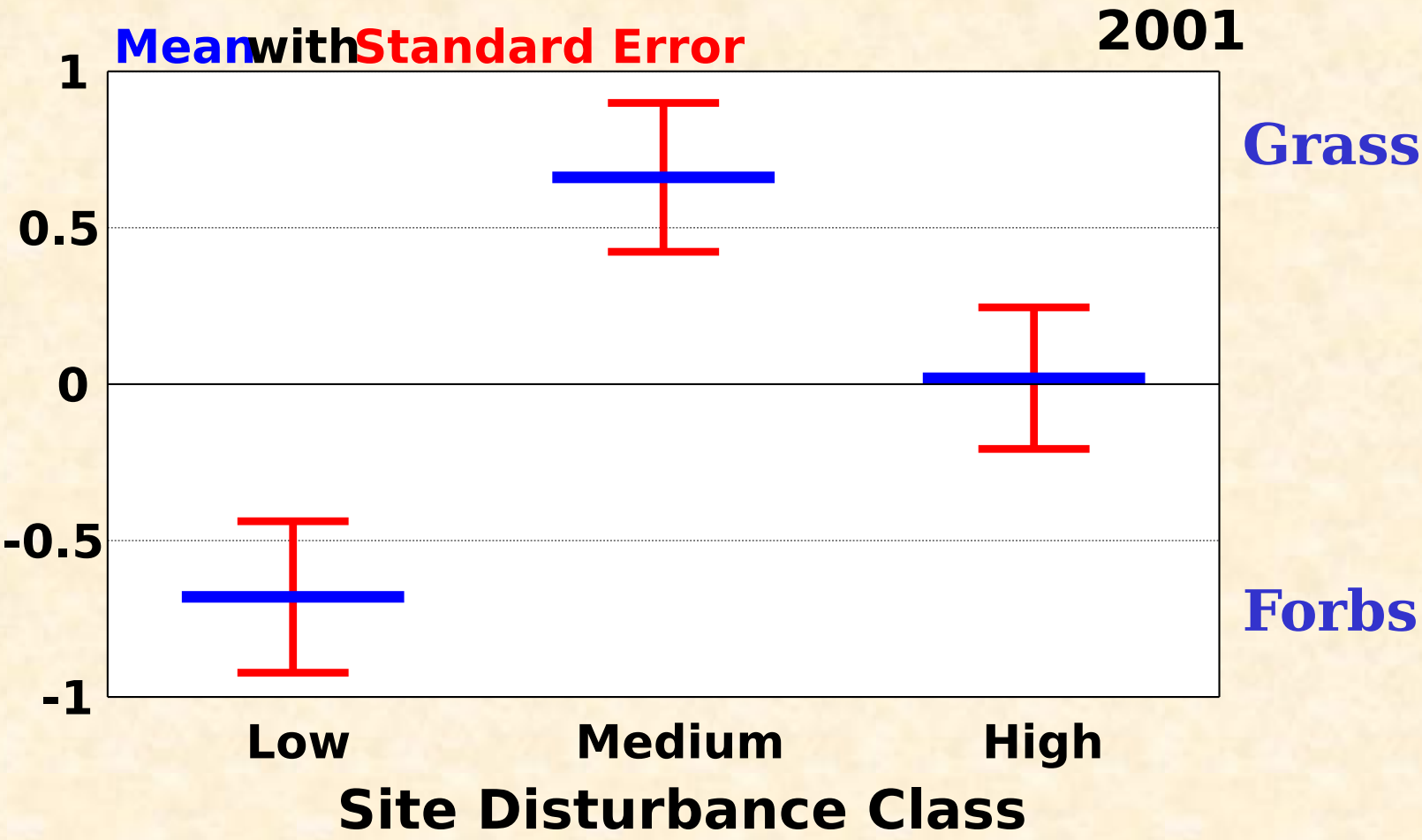
Woody Speci

Richn

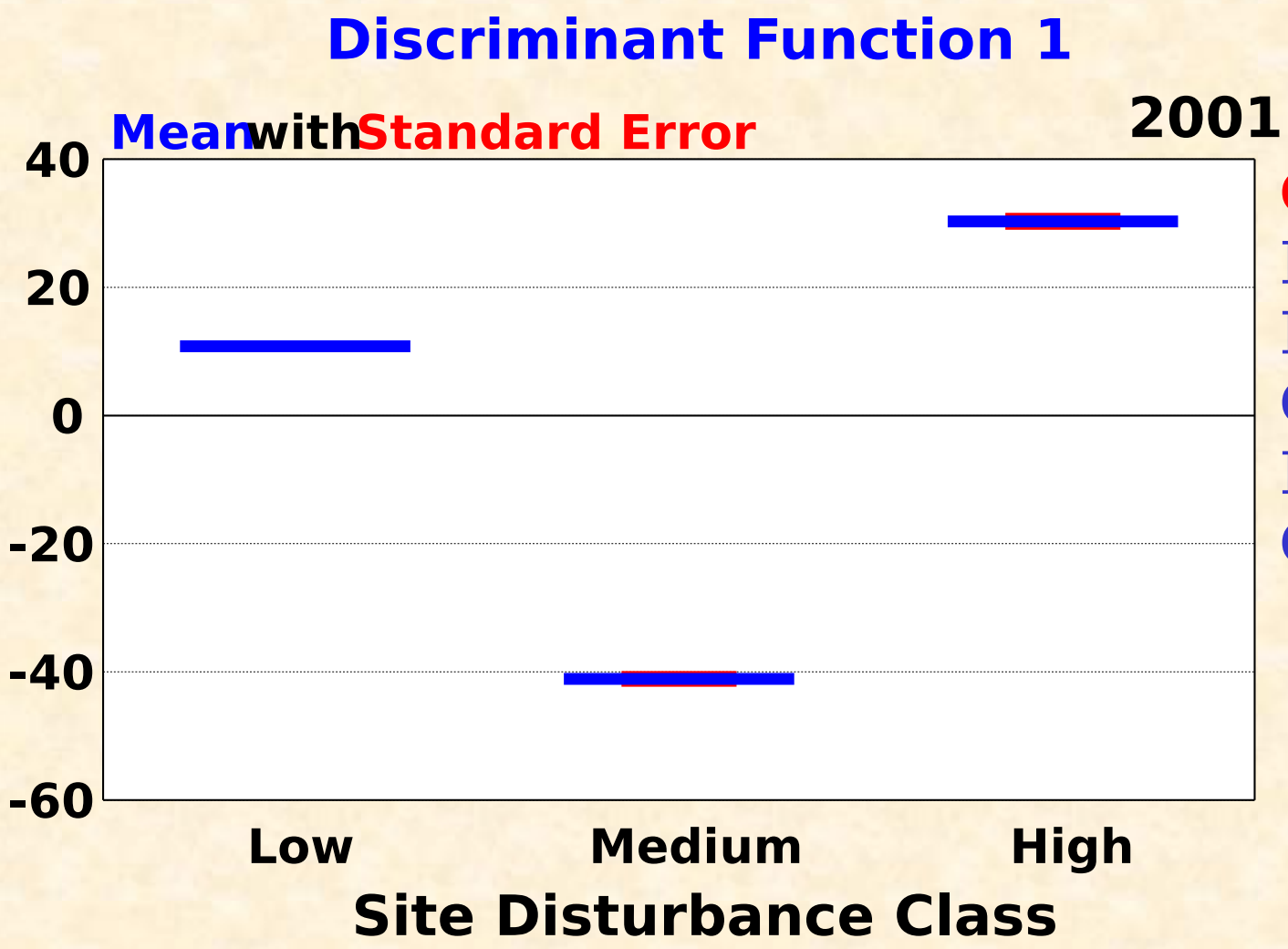
Bare Ground

General Ground Cover Variables

Discriminant Function 2

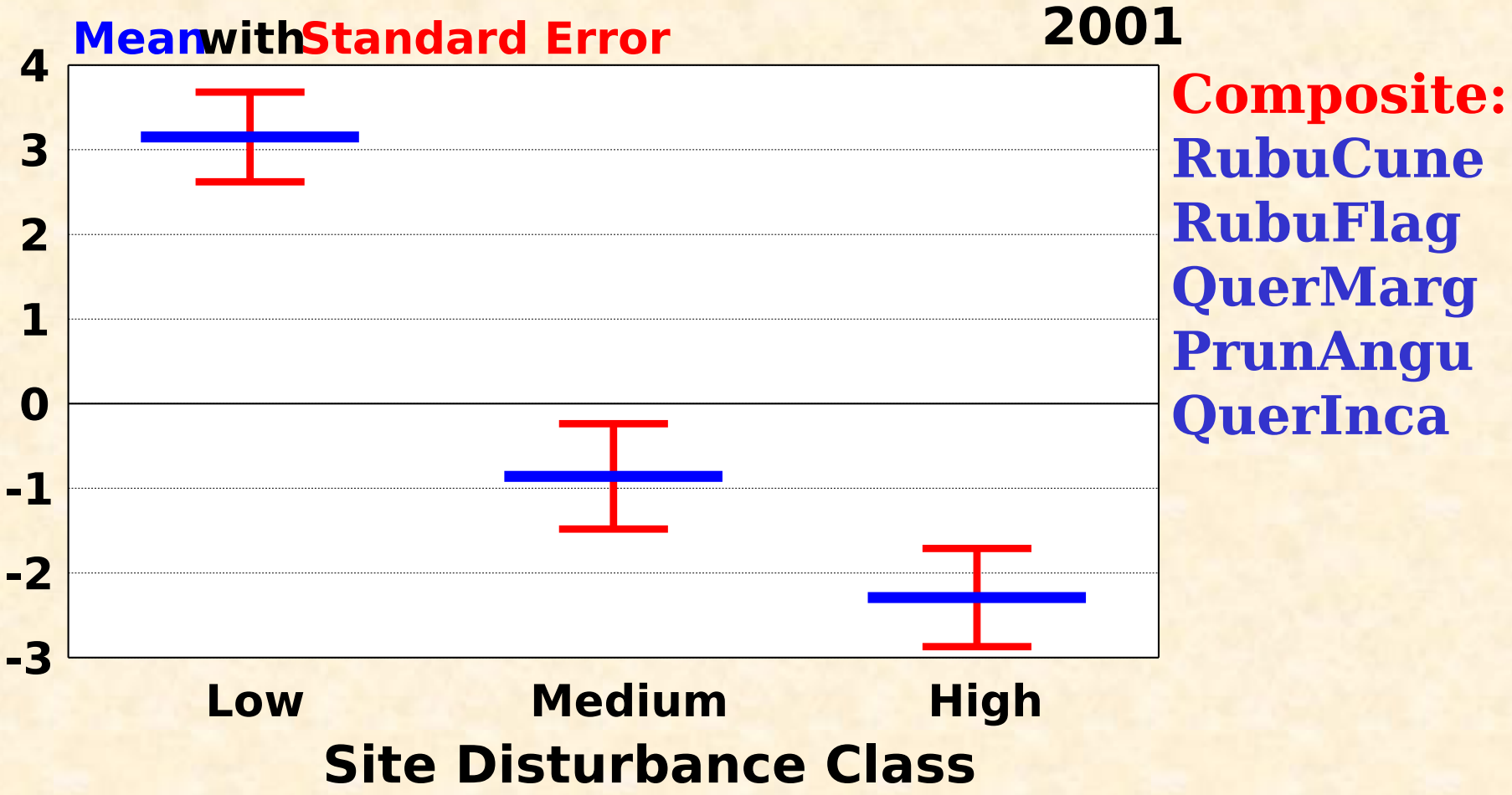


Woody Ground Cover



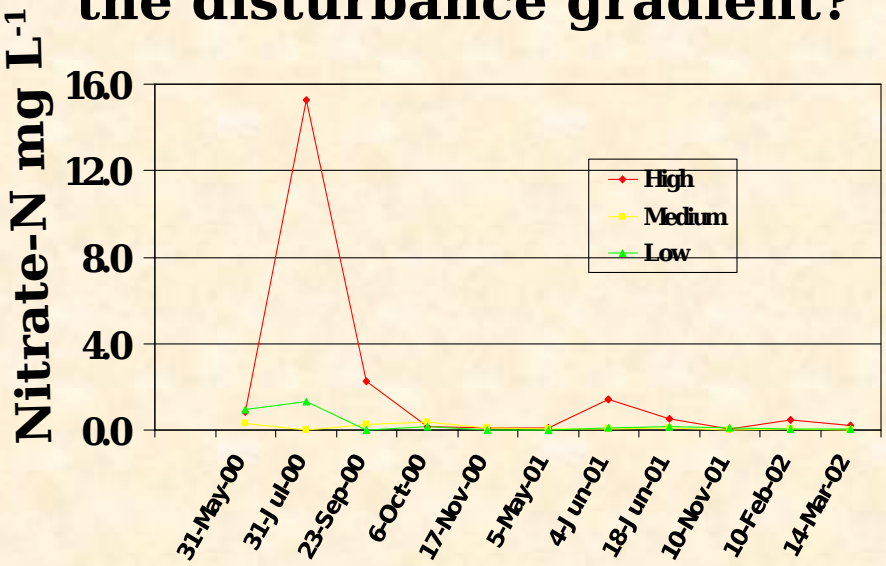
Composite:
RubuCune
RubuFlag
QuerMarg
PrunAngu
QuerInca

Woody Ground Cover



Nutrient Leakage
(Nitrate – NO_3^-)

How does nutrient leakage vary along the disturbance gradient?



cosystem resilience depends on nutrient retention

Similar pattern for:

NH_4^+ PO_4^{-3} SO_4^{-2} Cl^-

Ca^{+2} Mg^{+2} K^+ Na^+

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Soil Organic Carbon (g/m^2)

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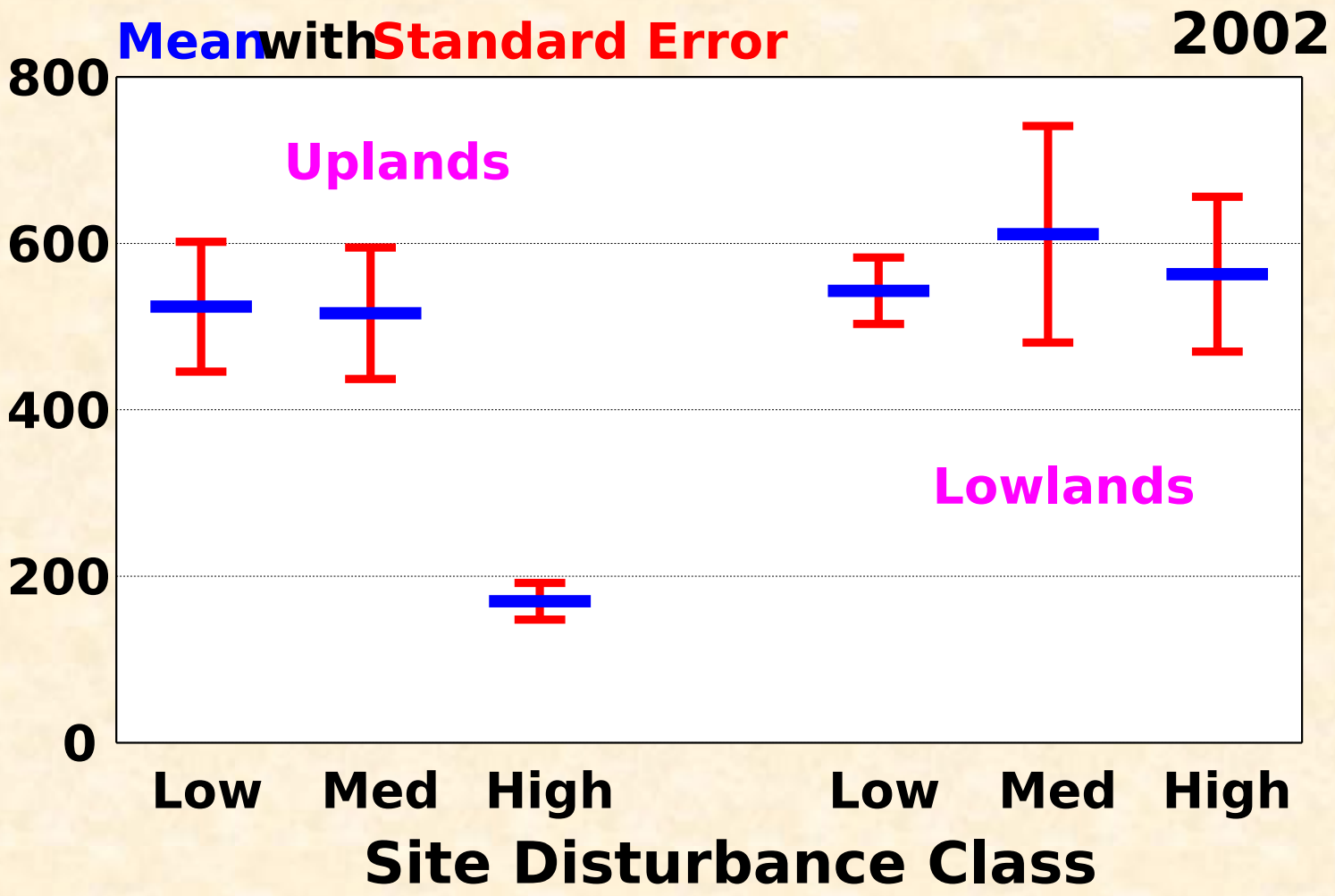
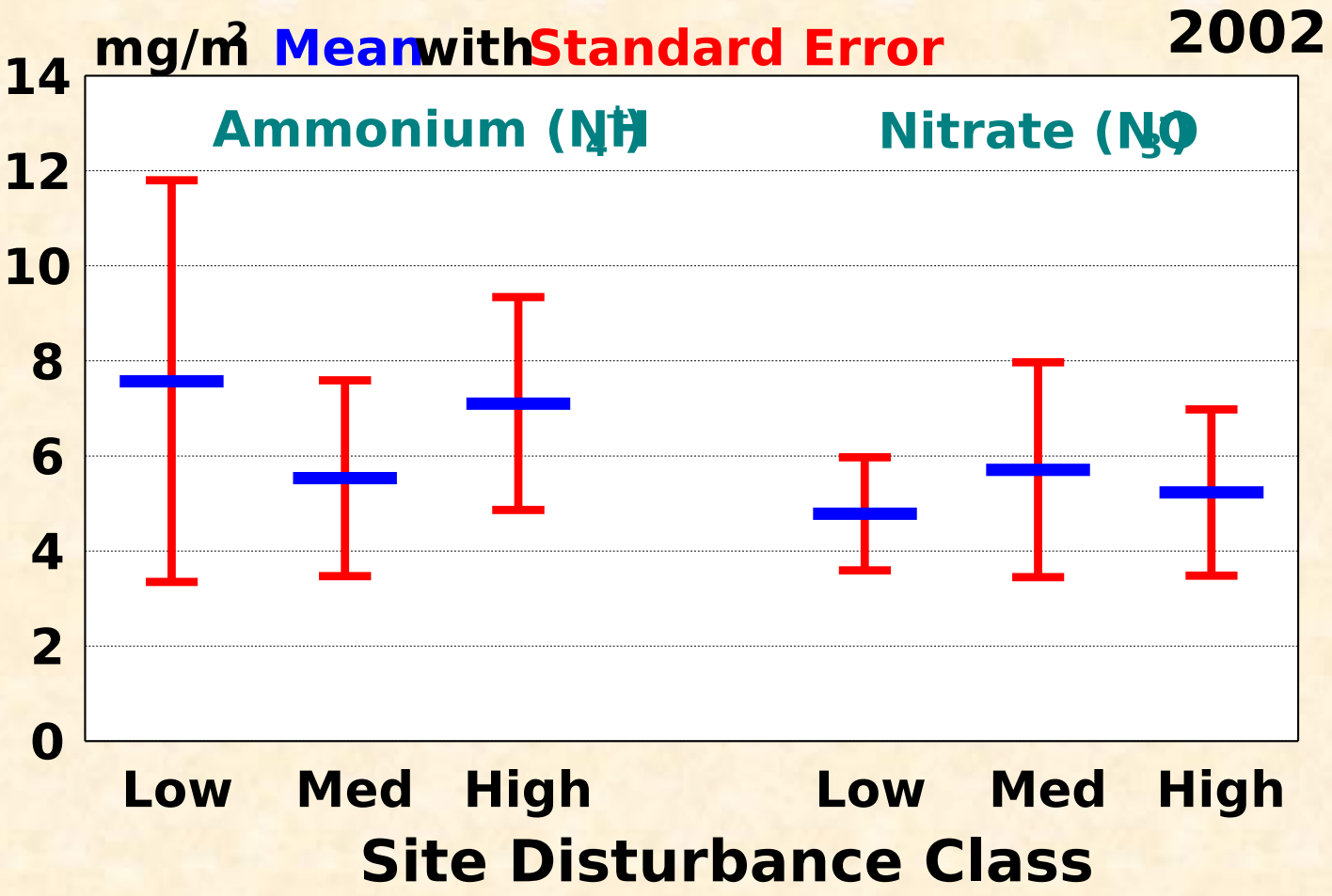


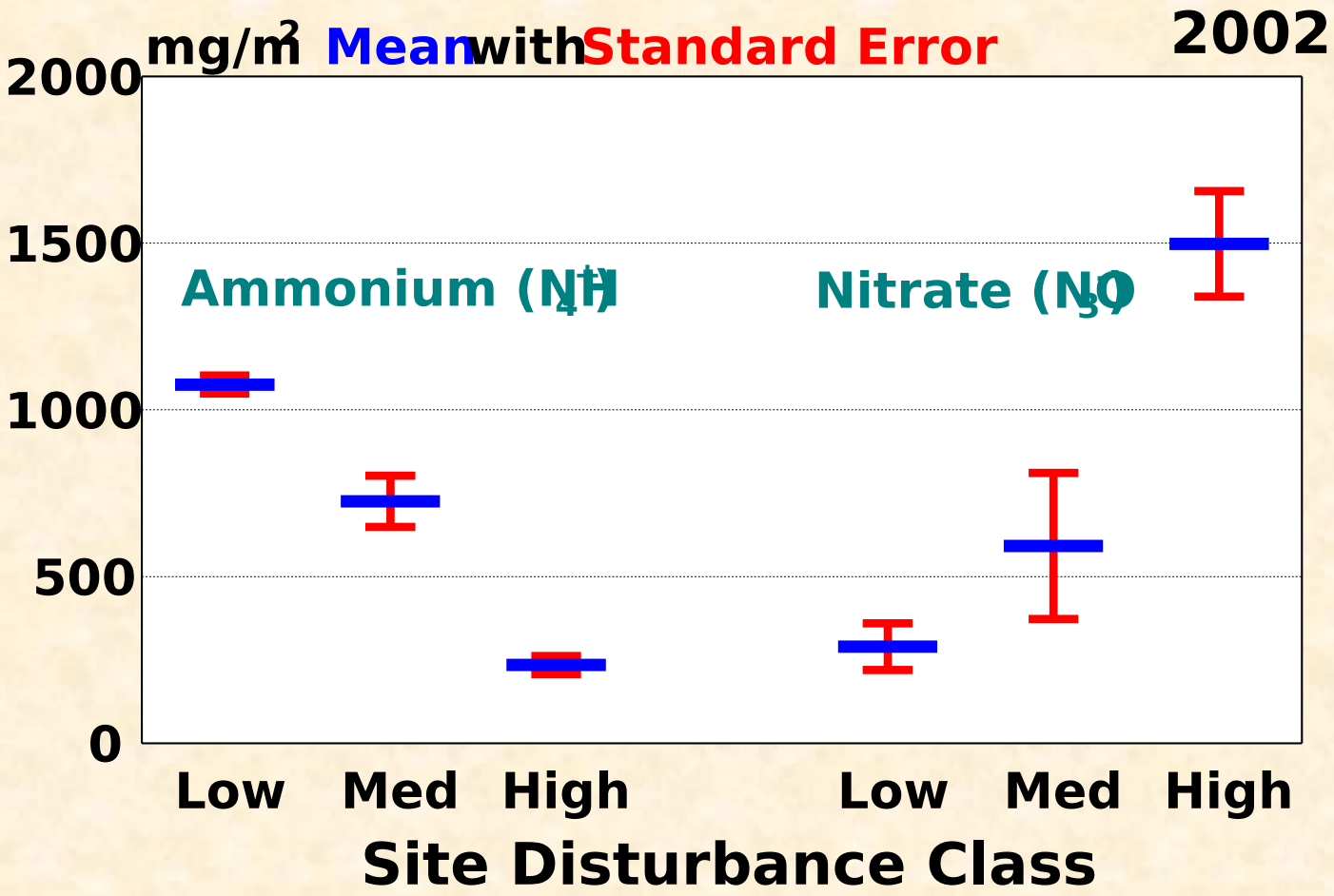
Soil Nitrogen Dynamics

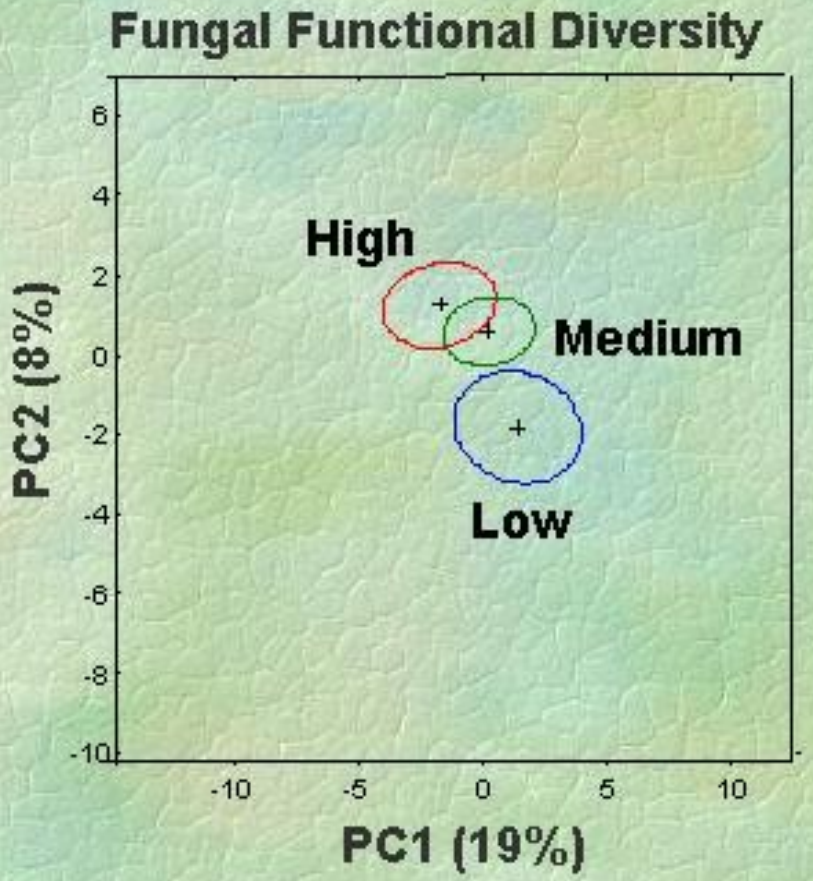
Initial Soil Concentrations



Soil Nitrogen Dynamics

4 Weeks Incubation in Lab




Fungal Functional Diversity
High
Medium
Low
PC2 (8%)
PC1 (19%)
6
4
2
0
-2
-4
-6
-8
-10
-10
-5
0
5
10

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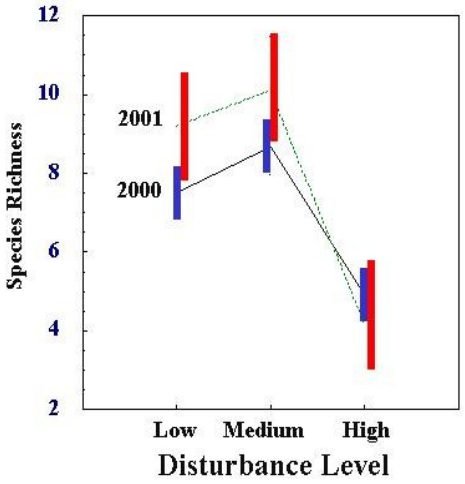
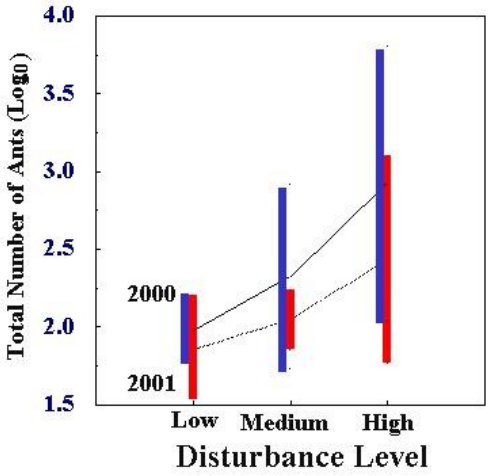
Ant Communities

Ant Species Richness

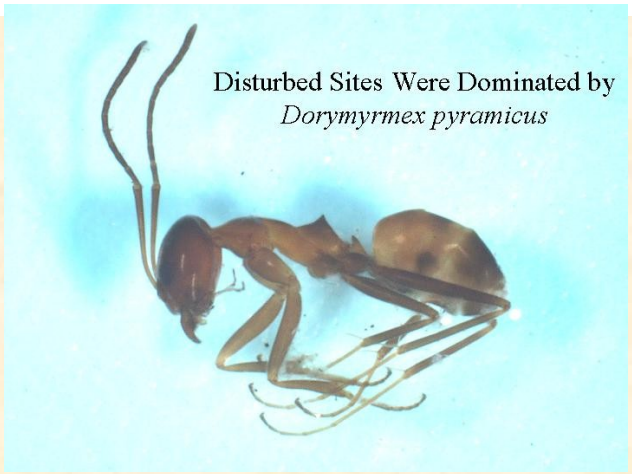


$P < 0.05$

Ant Abundance

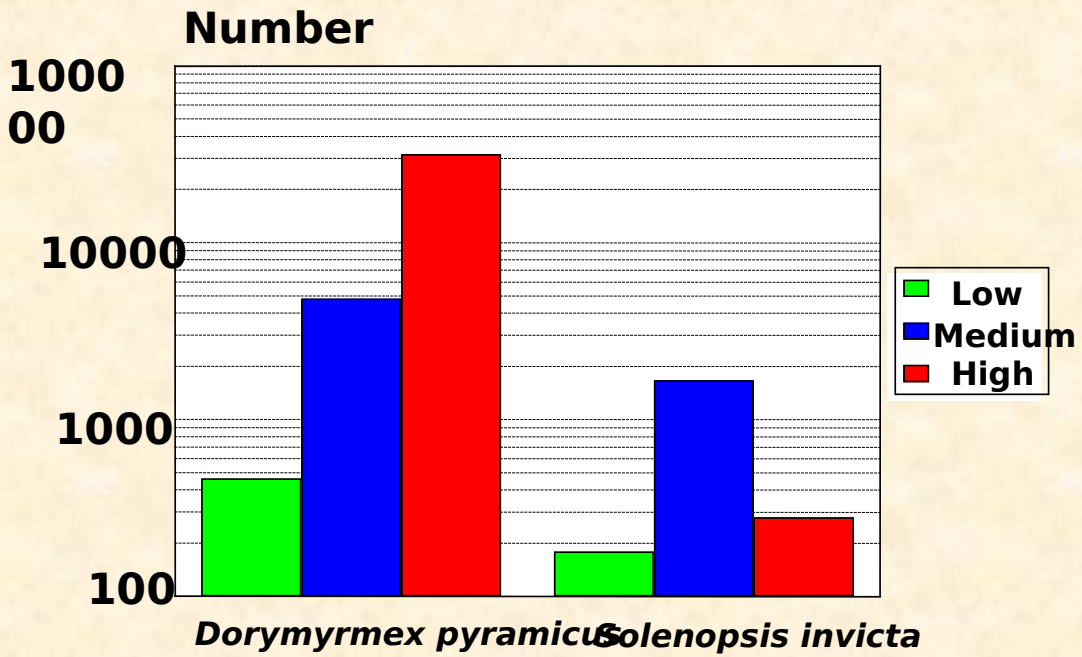


$P > 0.05$

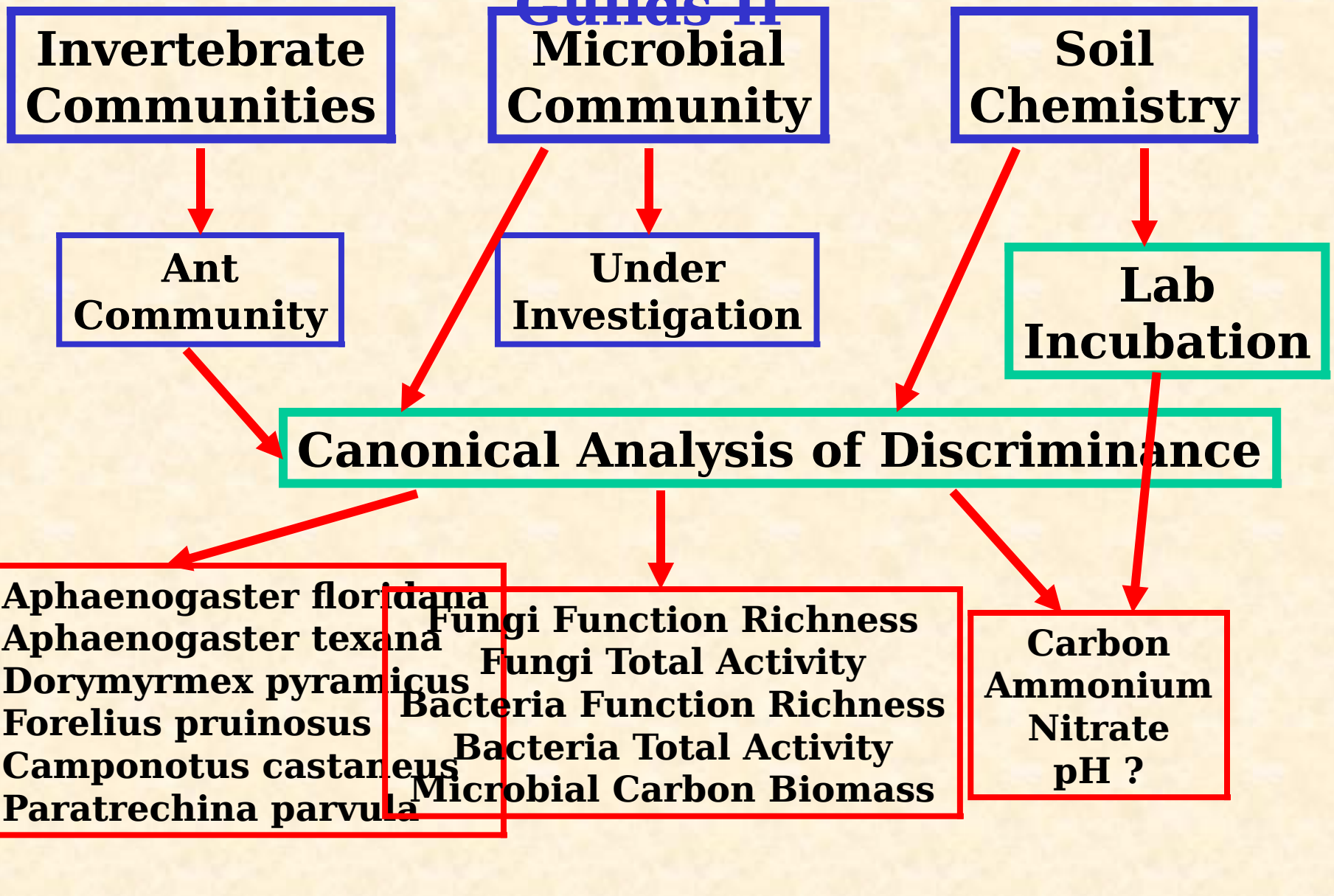


Number of Ants in Pitfall Traps (2000)

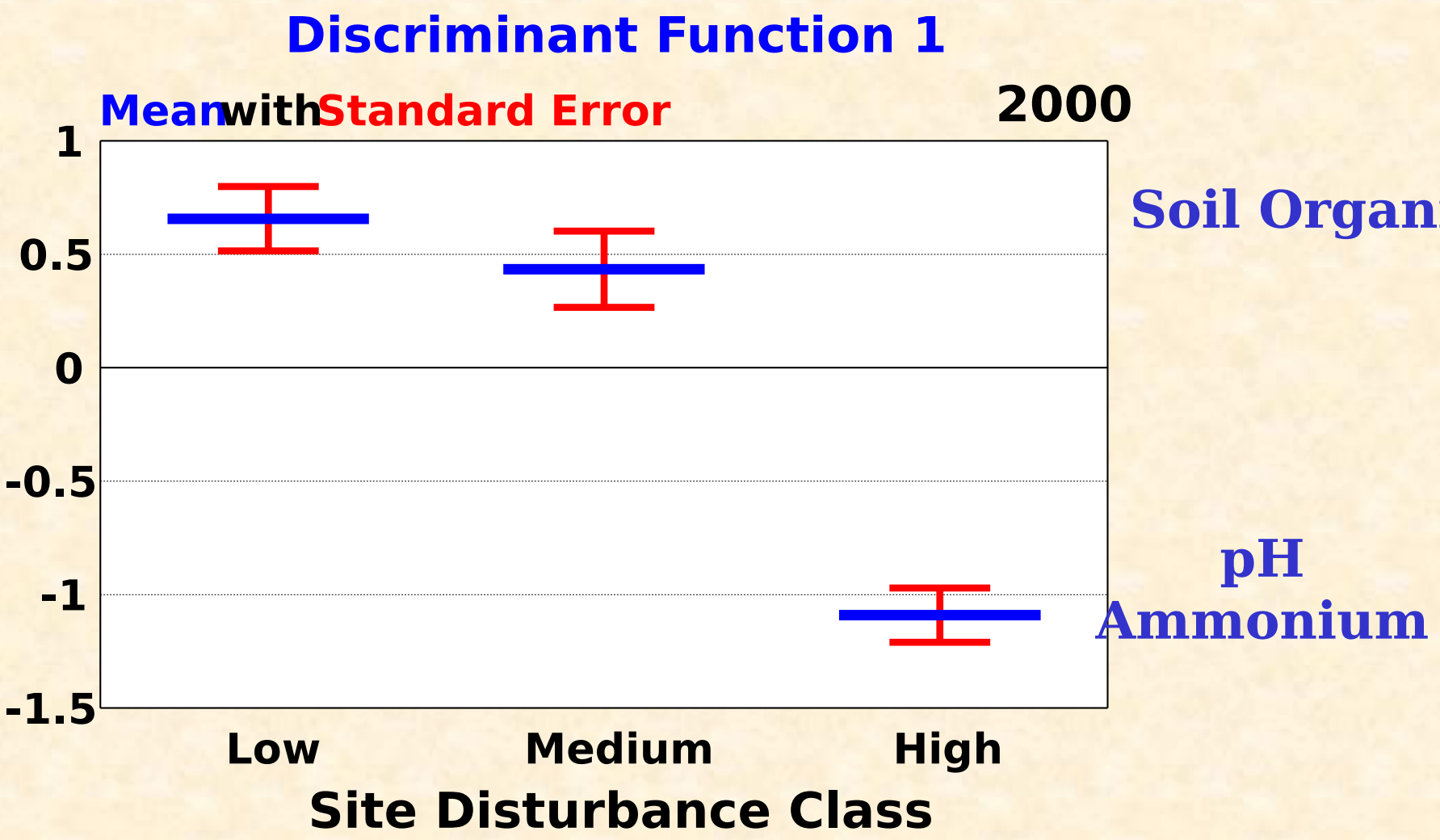
N = 60



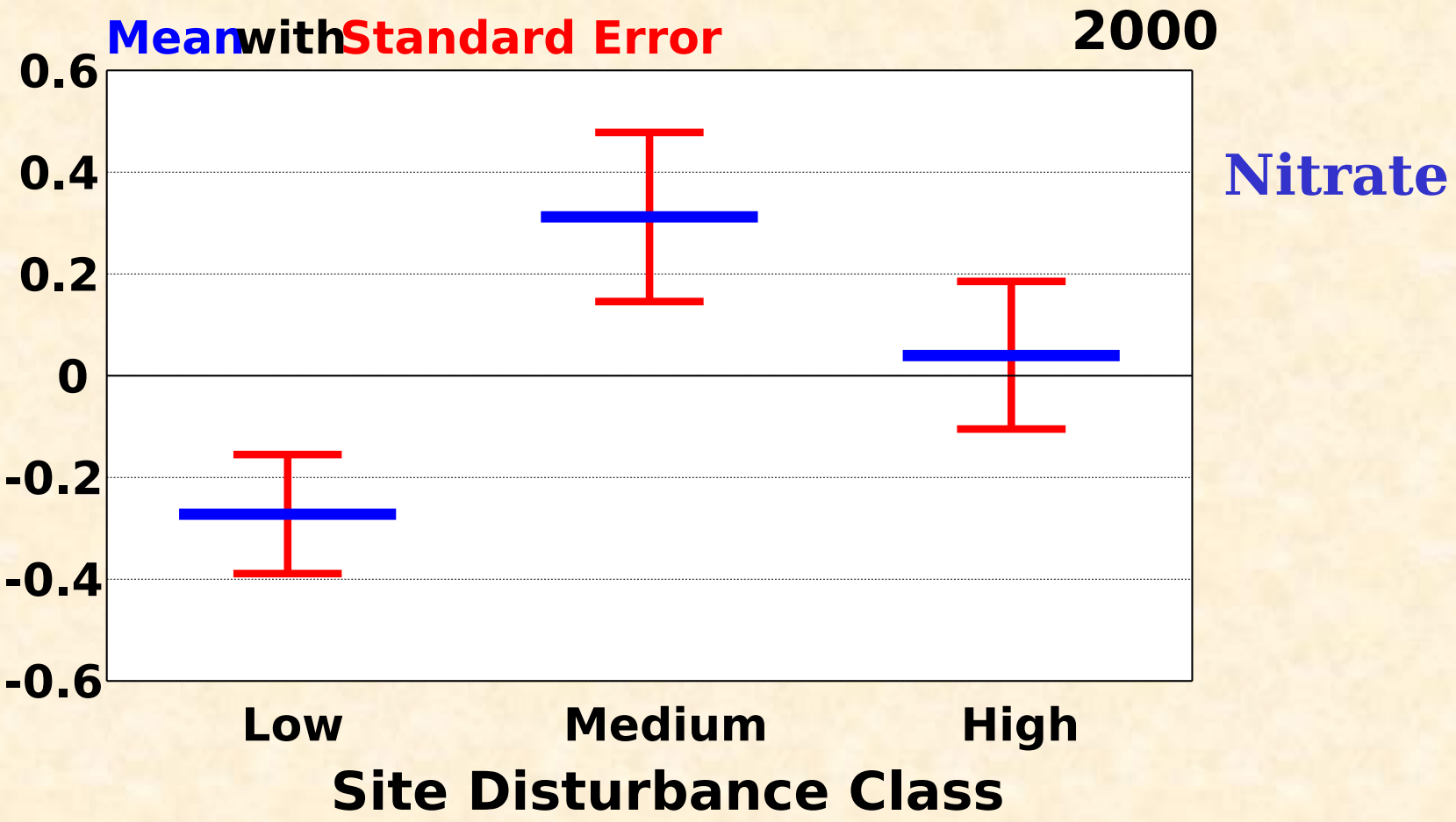
Constructing Ecological Indicator Guilds II



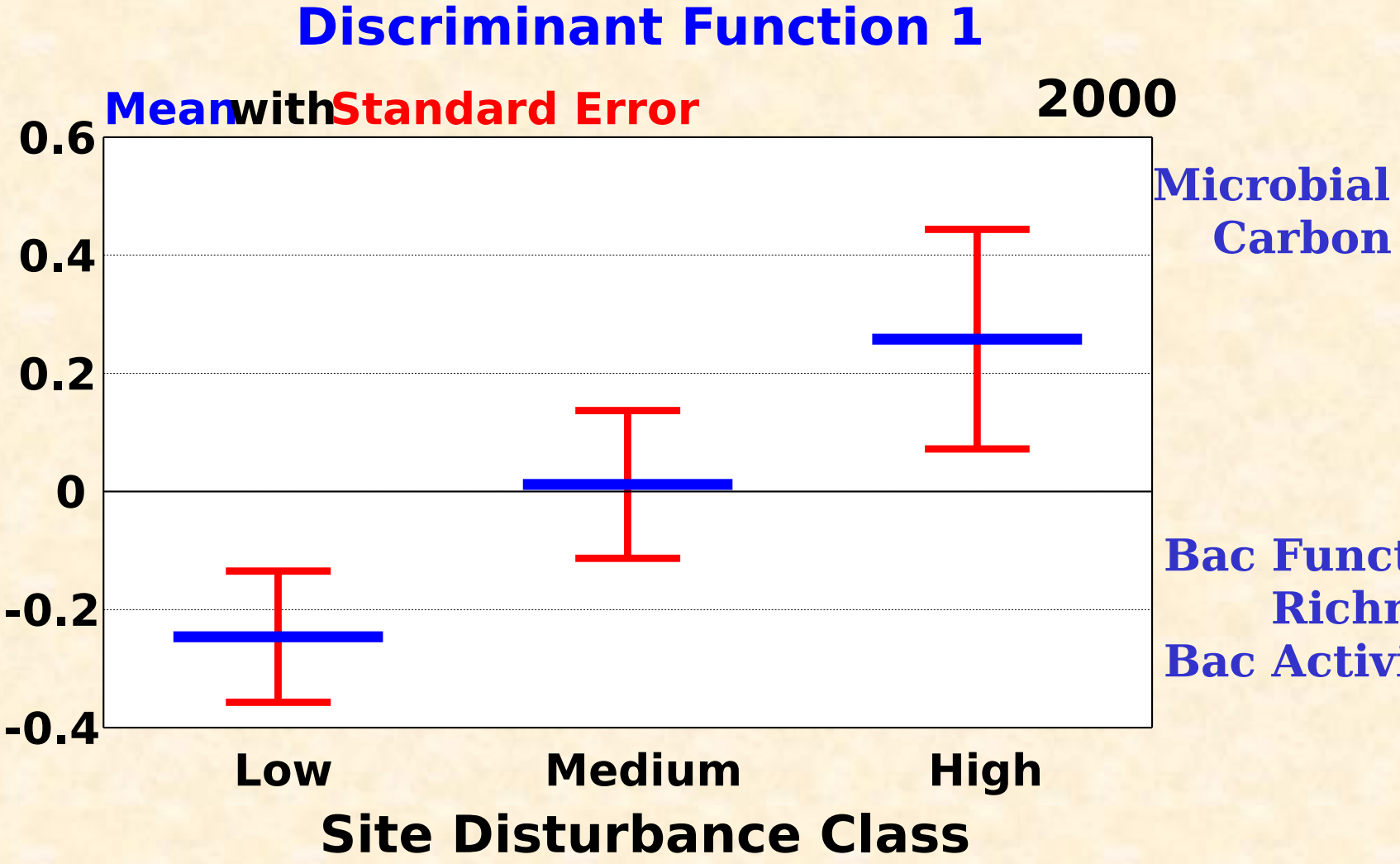
Soil Chemistry



Soil Chemistry



Microbial Community



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Microbial Community

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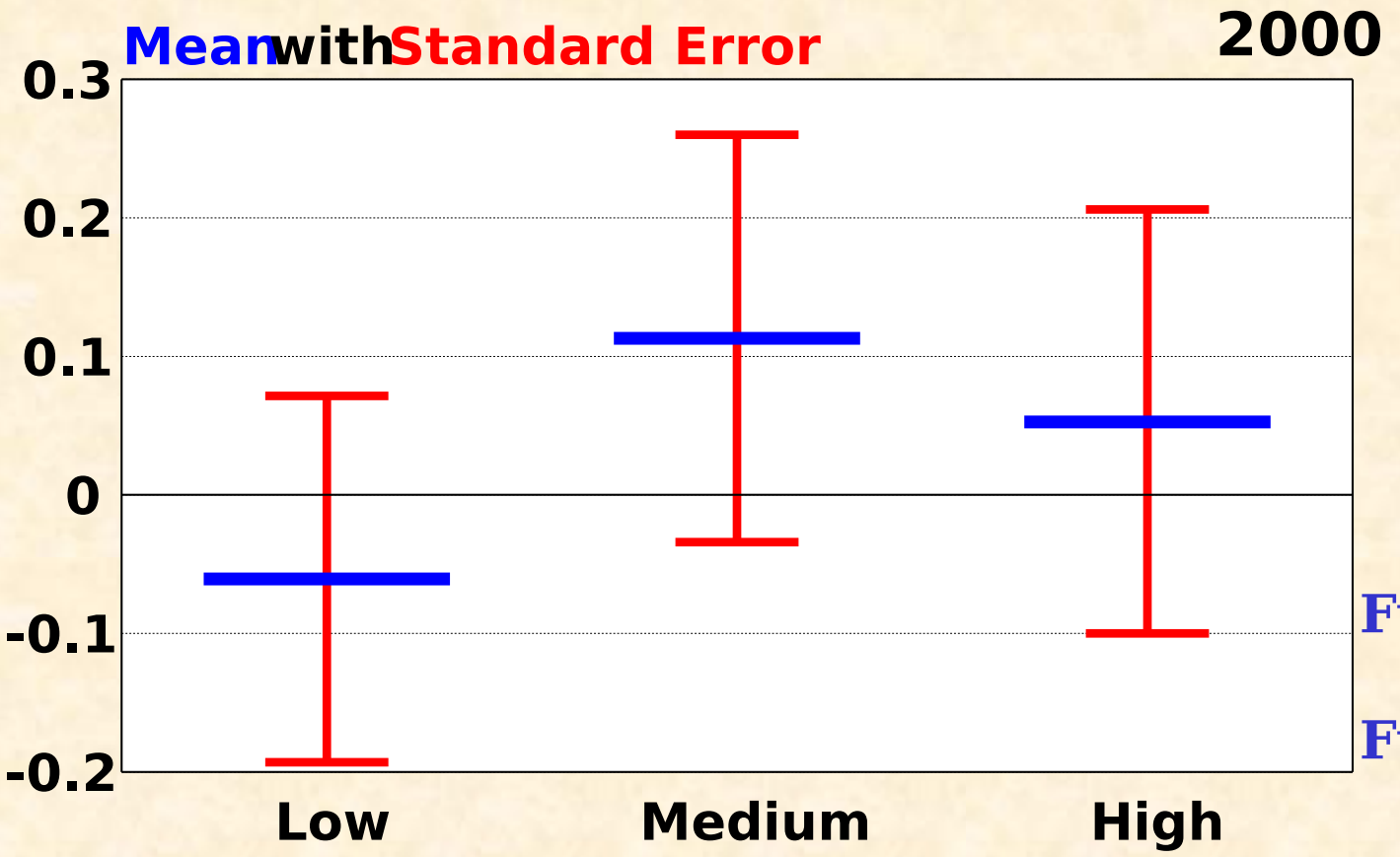
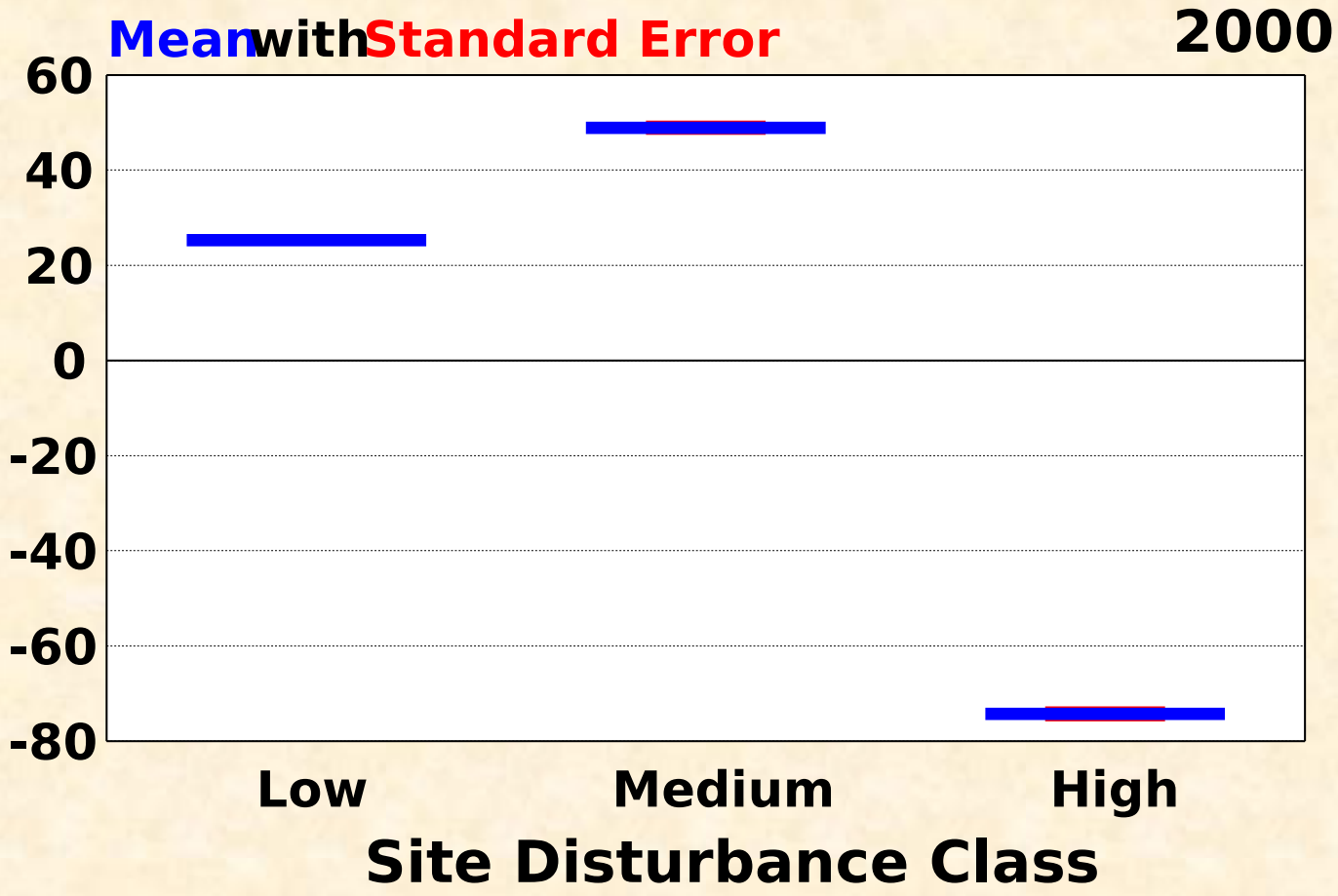
Discriminant Function 2



Fungi Functio
Richne
Fungi Activity

Ant Community



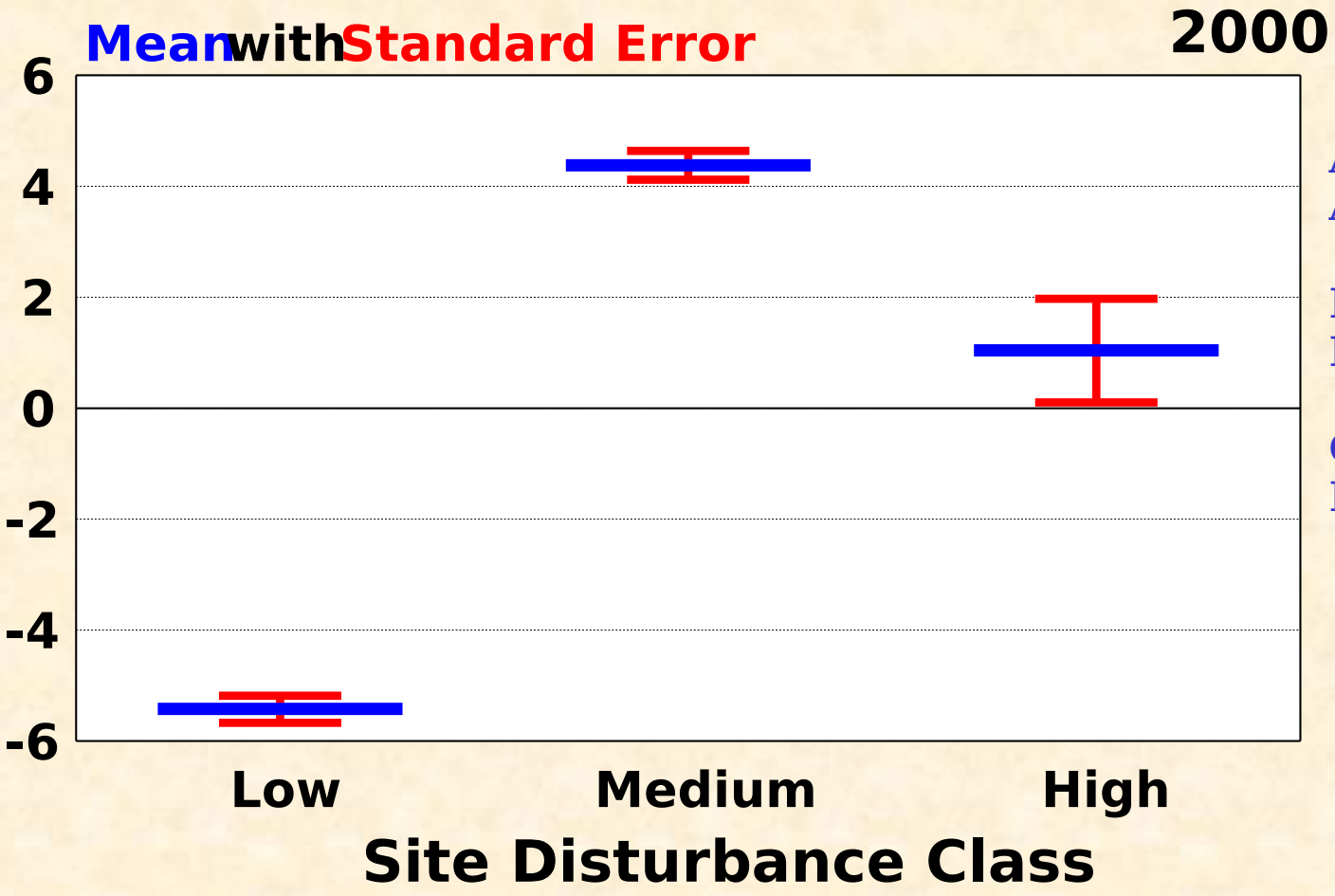
Aphaenogaster flori
Aphaenogaster texa

Dorymyrmex pyrami
Forelius pruinosus

Camponotus castan
Paratrechina parvul

Ant Community

Discriminant Function 2



Aphaenogaster flori
Aphaenogaster texa

Dorymyrmex pyrami
Forelius pruinosus

Camponotus castan
Paratrechina parvul

Development Instability

Measured by Fluctuating Asymmetry

- The departure from bilateral symmetry
- Attributed to physical or chemical stress in early development
- Simple leaves
  - Tooth counts
  - Lobe metrics
    - Vein lengths
    - Lobe widths
- Compound leaves
  - As in simple leaves
  - Number of leaflets
  - Size metrics of leaflet pairs

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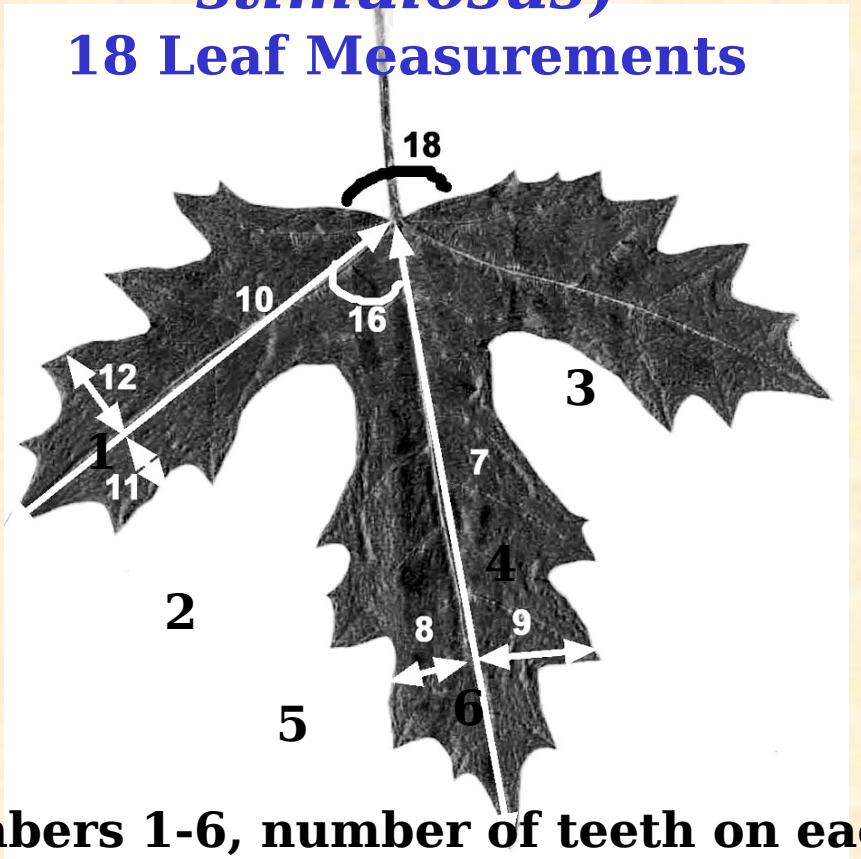
Tred-Softly (*Cnidoscolus stimulosus*)

18 Leaf Measurements



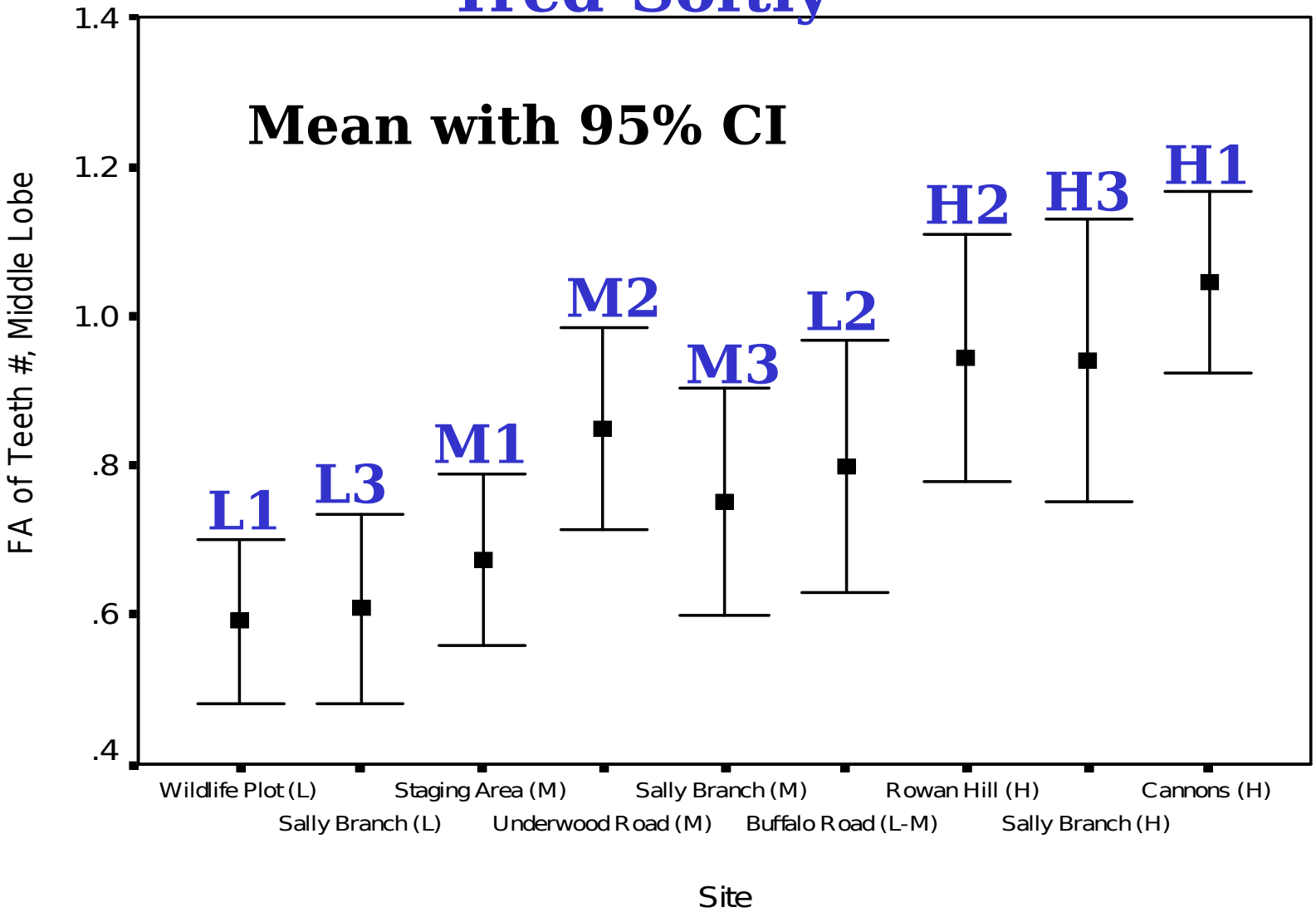
Numbers 1-6, number of teeth on each side of each lobe

7, 10, 13, vein length of each lobe

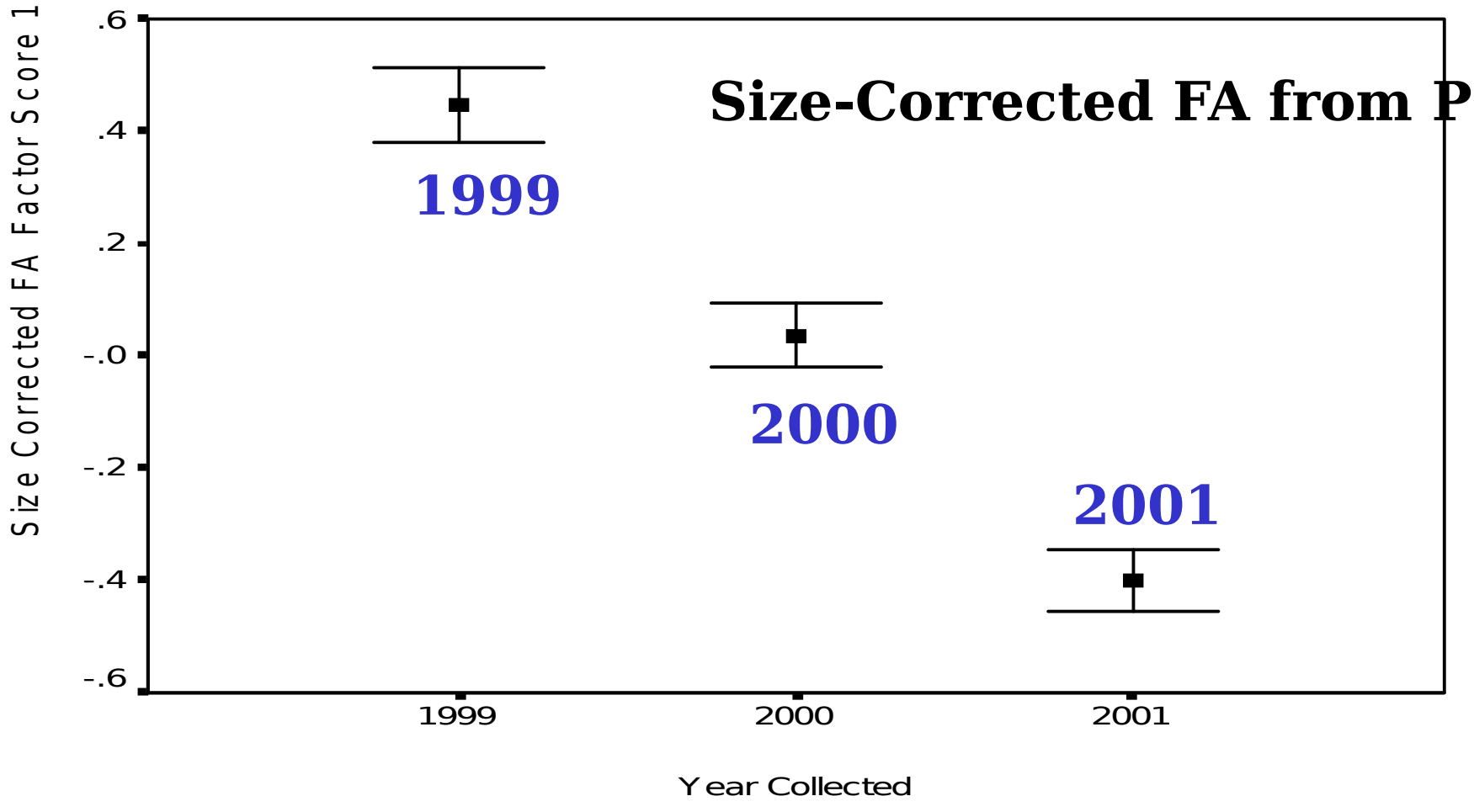
8-9, 11-12, 14-15 vein-leaf edge widths on each lobe

16-17 vein angles, 18 lobe angle at petiole

Fluctuating Asymmetry in Tred-Softly



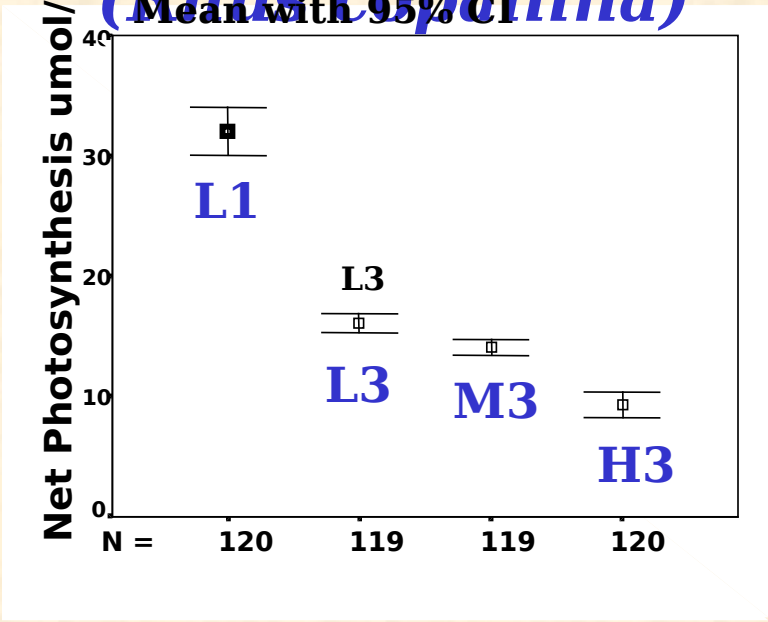
Fluctuating Asymmetry in Winged-Sumac



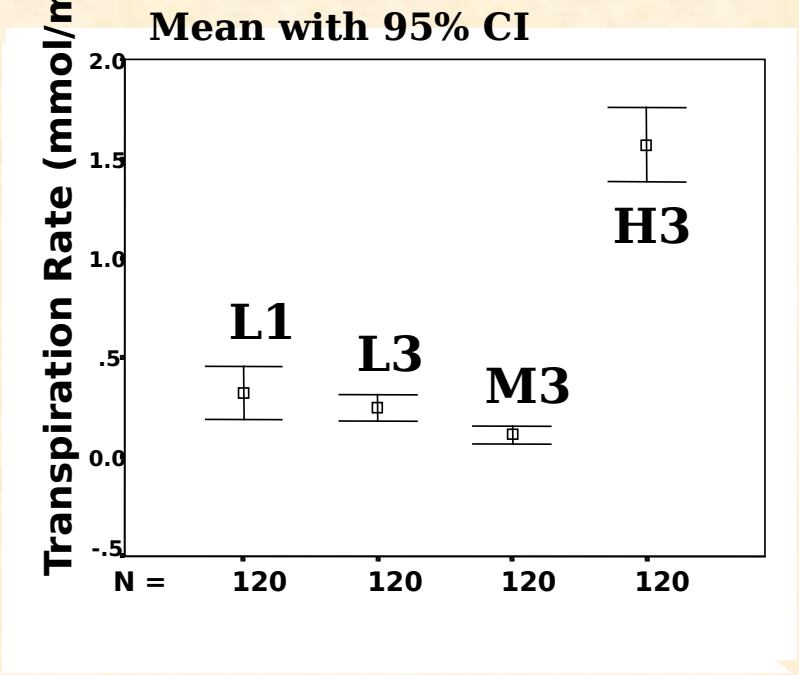
Development Instability
Current Conclusions

- Over 5,000 plants were examined
- Over 200,000 measurements were made
- DI and plant physiological metrics demonstrated that plants are stressed at HIGH disturbance sites
- Forbs were more sensitive than woody plants
- Drought had more effect than habitat disturbance
- Combinations of species and characters provided more reliable DI metrics

Net Photosynthesis for Winged Sumac *(Rhus copallina)*



Transpiration Rate for Winged Sumac *(Rhus copallina)*



Major Findings

Low–Medium–High disturbance gradient effectively characterized by Ecological Indicator Guilds derived by Discriminant Analysis of Ecological Indicator Systems

- **Habitat Metrics**
- **Invertebrate Communities (ANTS)**
- **Microbial Community**
- **Soil Chemistry**

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Major Findings

- **Multiple Indicator Systems (Guilds) will be required to monitor Ecological Conditions – Trends – Thresholds**
- **Some Ecological Indicators demonstrated that natural disturbance (e.g., drought) exert a Greater Effect than habitat disturbance**
- **BUT less disturbed habitats exhibit a Resilience or buffering against perturbations**
- **Less disturbance sites appear to be more Stable on the basis of important Ecological Indicators:**
  - **Larger carbon pool**
  - **Faster nutrient regeneration**
  - **Lower nutrient leakage**

Deliverables

- Ecological Indicators for land management
- Methodology for developing Ecological Indicators (statistical and modeling approaches)
- Metrics for classifying land disturbance (Site Index)
- Identification Key for Fort Benning Ants, Orthopterans, and Spiders (genera)
- Peer-reviewed articles
- Presentations and posters
- Extensive ecological database for data depository

Deliverables

Presentations:

Ecological Society of America Meeting, Tucson, AZ, 8/02
Soil Ecology Society Meeting, Calloway Gardens, GA, 5/01

Posters:

SERDP Symposium, Washington, D.C., 12/02
American Society of Agronomy Meeting, Indianapolis, IN, 11/02
Ecological Society of America Meeting, Tucson, AZ, 8/02
Student Research, Berry College, GA, 4/02
2 at SERDP Symposium, Washington, D.C., 11/01
2 at Student Research, Berry College, GA, 4/01

Publications:

1 Submitted to Mycologia
16 manuscripts are in preparation

Slides for Background and Additional Information

PERFORMERS
and Their Technical Specialties

Dr. Anthony J. Krzysik

Prescott College

Project Leader, Specialist in vertebrate, statistical, community, and field ecology

Dr. Harold E. Balbach

U.S. Army – ERDC – CERL, Specialist in ecology and military land management

Dr. John M. Emlen

USGS – BRD - WFRC, Specialist in theoretical ecology and ecological modeling

Dr. D. Carl Freeman

Wayne State University, Specialist in plant physiological and evolutionary ecology

Dr. John H. Graham

Berry College, Specialist in invertebrate, physiological, and genetic ecology

Dr. David A. Kovacic

University of Illinois, Specialist in ecosystems ecology, wetlands, nutrient dynamics

Dr. John C. Zak

Texas Tech University, Specialist in microbial and soil ecology

Ecological Indicator Design Criteria

Modified from Proposal, Table 1 (1998)

- Ease of use for land managers
- Cost effective
- Ecological relevance & value
- Reflect ecosystem dynamics and physiological stress
- Quantifiable with statistical estimates of accuracy & precision
- Robust & multi-scale
- EcoRegion application
- Global methodology extension
- Symmetry: track degradation & recovery/restoration
- Reasonable response times
- Reliable, consistent, unambiguous
- Incorporation of natural variance
- Known sensitivity to temporal sampling window
- Association with suites of stressors

Application of Ecological Indicators for Military Land Management

- Training sustainability
- Ecosystem maintenance and sustainability
- Long-term productivity
- Multiple-use decisions and requirements
- Conditions & Trends in natural resources
- Timing and success of restoration efforts
- Environmental monitoring
- Legal mandates

Discriminant Analysis

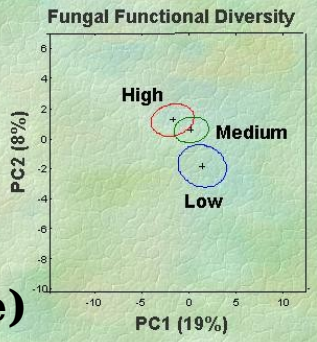
- Discriminant analysis weights the selected predictor variables (e.g., canopy cover, poison ivy cover, A-horizon soil depth, mockernut hickory density)
- Such that their linear combinations maximally distinguish (discriminate) among two or more predetermined groups (e.g., the 3 site disturbance classes)
- The first discriminant function possesses the highest discriminating power
- The second discriminant function is uncorrelated with the first (orthogonal) and is the next highest in discriminating power

Microbial and Soil Ecology

Microbial and Nitrogen Dynamics Differ Along the Disturbance Gradient

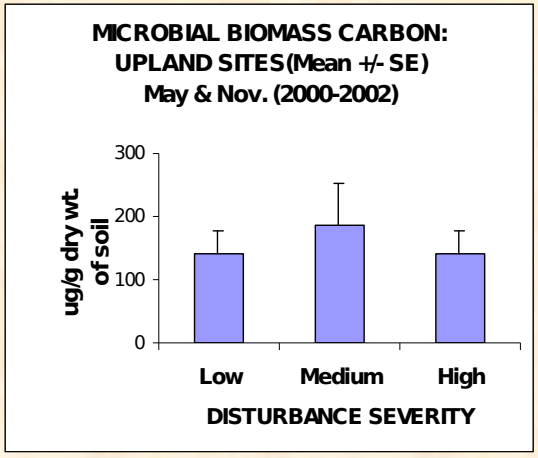
Note Reduced Microbial Carbon:
Low sites have higher turnover rates (biotic response)
High sites have higher soil temperatures and lower soil moisture (abiotic response)

Fungal Functional Diversity

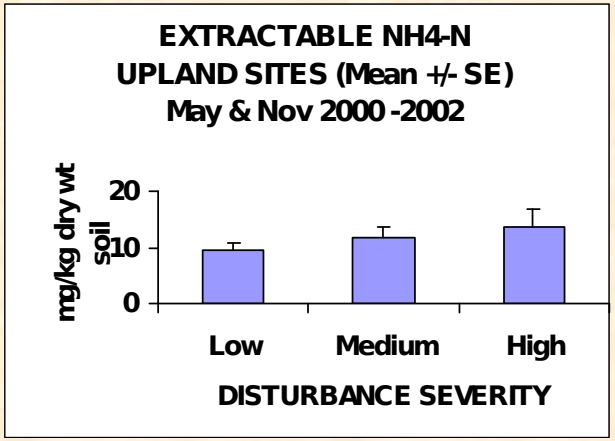


Principal Components Analys

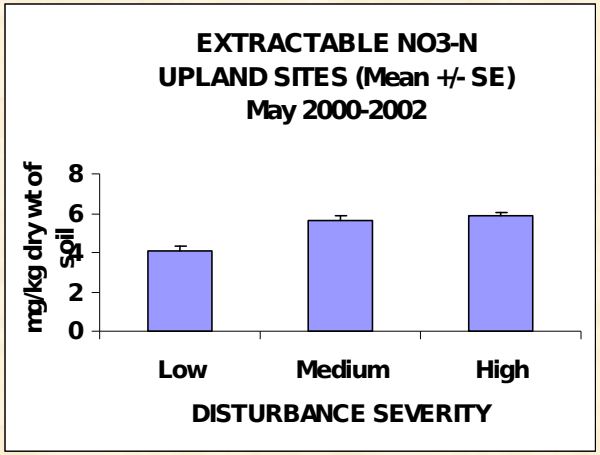
Microbial Carbon



Ammonium



Nitrate



Note higher nitrogen use at Low sites